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HIGH LEVEL CONTAINER

Anthony L. Farinacci, et al

AAI Corporation

Prepared for:

Army Natick Laboratories

March 1973

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Airdrop operations	4		7		4	
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Aerospace environment			6			
Navigation			6			
Air navigation			6			
Extraction			7			
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Equations of motion					8	
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TECHNICAL REPORT 73-55-AD

HIGH LEVEL CONTAINER
AIRDROP SYSTEM

FINAL REPORT

By

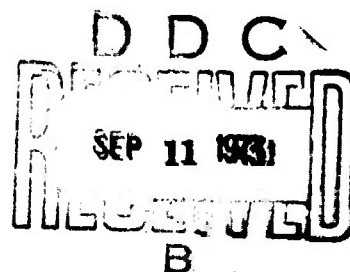
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March 1973

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For

Airdrop Engineering Laboratory
U. S. Army Natick Laboratories
Natick, Massachusetts

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FOREWORD

This program was conducted by AAI Corporation, Cockeysville, Maryland for the Airdrop Engineering Laboratory, U. S. Army Natick Laboratories, Natick, Massachusetts under Contract DAAG17-72-C-0075. The purpose of the program was to identify feasible approaches for achieving the capability of airdropping container loads weighing up to 2200 lbs. from high levels and landing them with a high degree of single-drop accuracy and minimum multiple-drop dispersion. The study concentrated mostly on the definition of feasible concepts and analyses to determine their potential in satisfying the design requirements. Results are presented along with recommendations for the most feasible system.

The program was performed under the direction of George Barnard of Natick Laboratories. The project was managed at AAI Corporation by W. L. Black under the supervision of R. G. Strickland, Department Manager. The principle investigators and contributors were D. B. Bruner, R. S. Payne and A. L. Farinacci.

TABLE OF CONTENTS

<u>Title</u>	<u>Page</u>
I. INTRODUCTION	1
II. GOALS AND REQUIREMENTS	2
III. PROBLEM DISCUSSION	4
IV. TECHNICAL INVESTIGATIONS	6
A. Study Methodology	6
1. General Method	6
2. Background Studies	8
a. Wind Conditions	8
b. Cargo Stabilization Study	21
c. Extraction Study	26
3. Computer Model	32
B. Concept Description	38
1. Standard Container Airdrop System	38
2. Stabilization Methods	40
a. Recovery Parachute Systems	40
b. Staged Deceleration Systems	40
3. Extraction Systems	42
a. Gravity Extraction	42
b. Group Extraction	42
4. Release Point Selection and Acquisition	45
5. Parachute Altitude Recognition System	47
C. Results of Analyses	48
1. Extraction Systems	48

TABLE OF CONTENTS (continued)

<u>Title</u>	<u>Page</u>
a. Gravity Extraction	48
b. Parachute Extraction	48
2. Wind Effect Study	52
3. Effect of Aircraft Heading	75
4. Effect of Stabilization Parachute	75
5. Effect of Cargo Weight	76
6. Effect of Cargo Release Altitude	77
7. Effect of Air Temperature	77
8. High Velocity vs Low Velocity Impact	84
9. Statistics of Delivery Accuracy	87
10. Summary of Parametric Effects	94
a. Staging Height	94
b. Cargo Release Velocity	95
c. Rotational Velocity of Cargo	95
d. Height Above Drop Zone	95
e. Inflation Time of the Recovery Parachute	96
f. Cargo Weight	96
g. Elevation of Drop Zone Above MSL	97
h. Accuracy of Altitude Sensing Device	97
11. Comparative Cost Model	99
D. Recommended Configuration	102
V. CONCLUSIONS AND RECOMMENDATIONS	107
LIST OF REFERENCES	110

LIST OF ILLUSTRATIONS

<u>FIGURE NO.</u>	<u>TITLE</u>	<u>PAGE NO.</u>
1	WIND VECTORS	10
2	WIND VECTORS CONTINUED	11
3	WIND VECTORS CONTINUED	12
4	HLCADS WIND CASE NO. 32	13
5	HLCADS WIND CASE NO. 42	14
6	HLCADS WIND CASE NO. 50	15
7	HLCADS WIND CASE NO. 75	16
8	HLCADS WIND CASE NO. 77	17
9	HLCADS WIND CASE NO. 78	18
10	HLCADS WIND CASE NO. 83	19
11	HLCADS WIND CASE NO. 87	20
12	GRAVITY EXTRACTION - C130 AND C141 AIRCRAFT	29
13	PARACHUTE EXTRACTION - C130 AND C141 AIRCRAFT	30
14	PROPOSED CONFIGURATION FOR PARACHUTE EXTRACTION	43
15	CARGO SPREAD AT DROP ZONE - GRAVITY EXTRACTION	46
16	CARGO SPREAD AT DROP ZONE - PARACHUTE EXTRACTION	50
17	CARGO GROUND TRACK - WIND CASE 42 - 7' STABILIZATION PARACHUTE	53
18	CARGO GROUND TRACK - WIND CASE 51 - 7' STABILIZATION PARACHUTE	54
19	CARGO GROUND TRACK - WIND CASE 35 - 7' STABILIZATION PARACHUTE	55

LIST OF ILLUSTRATIONS
(continued)

FIGURE <u>NO.</u>	<u>TITLE</u>	PAGE <u>NO.</u>
20	CARGO GROUND TRACK - WIND CASE 17 - 7' STABILIZATION PARACHUTE	56
21	CARGO GROUND TRACK - WIND CASE 79 - 7' STABILIZATION PARACHUTE	57
22	CARGO GROUND TRACK - WIND CASE 78 - 7' STABILIZATION PARACHUTE	59
23	CARGO GROUND TRACK - WIND CASE 50 - 7' STABILIZATION PARACHUTE	60
24	CARGO GROUND TRACK - WIND CASE 32 - 7' STABILIZATION PARACHUTE	61
25	CARGO GROUND TRACK - WIND CASE 42 - 7' STABILIZATION PARACHUTE	62
26	CARGO GROUND TRACK - WIND CASE 83 - 7' STABILIZATION PARACHUTE	63
27	CIRCULAR ERROR USING ALTITUDE WIND - 7' STABILIZATION PARACHUTE	64
28	CIRCULAR ERROR USING GROUND - ALTITUDE WIND - 7' STABILIZATION PARACHUTE	65
29	CARGO GROUND TRACK - WIND CASE 50 - 4' STABILIZATION PARACHUTE	66
30	CARGO GROUND TRACK - WIND CASE 77 - 4' STABILIZATION PARACHUTE	67
31	CARGO GROUND TRACK - WIND CASE 75 - 4' STABILIZATION PARACHUTE	68
32	CARGO GROUND TRACK - WIND CASE 87 - 4' STABILIZATION PARACHUTE	69
33	CARGO GROUND TRACK - WIND CASE 78 - 4' STABILIZATION PARACHUTE	70

LIST OF ILLUSTRATIONS
(continued)

FIGURE NO.	<u>TITLE</u>	PAGE NO.
34	CARGO GROUND TRACK - WIND CASE 42 - 4' STABILIZATION PARACHUTE	71
35	CIRCULAR ERROR - ALTITUDE WIND - 4' STABILIZATION PARACHUTE	72
36	CIRCULAR ERROR - GROUND ALTITUDE WIND - 4' STABILIZATION PARACHUTE	73
37	CIRCULAR ERROR - REEFED G-12D PARACHUTE	74
38	CARGO GROUND TRACK - WIND CASE 78 - LIGHT CONTAINERS . .	78
39	CARGO GROUND TRACK - WIND CASE 42 - LIGHT CONTAINERS . .	79
40	CARGO GROUND TRACK - WIND CASE 50 - LIGHT CONTAINERS . .	80
41	CARGO GROUND TRACK - WIND CASE 32 - DROP ZONE AT 5000 FEET ABOVE MSL	81
42	CARGO GROUND TRACK - WIND CASE 50 - DROP ZONE AT 5000 FEET ABOVE MSL	82
43	CARGO GROUND TRACK - WIND CASE 32 - EXTREME TEMPERATURE EFFECTS	83
44	CARGO GROUND TRACK - WIND CASE 50 - HIGH VELOCITY IMPACT	85
45	CARGO GROUND TRACK - WIND CASE 32 - HIGH VELOCITY IMPACT	86
46	MEAN POINT OF IMPACT CONCEPT	89
47	CONCEPT OF CEP OF MPI'S	91
48	HLCADS - HIGH LEVEL CONTAINER AIRDROP SYSTEM	104
49	HLCADS - STABILIZATION PARACHUTE CONFIGURATION	105
50	HLCADS - RECOVERY PARACHUTE CONFIGURATION	106

LIST OF TABLES

<u>TABLE NO.</u>	<u>TITLE</u>	<u>PAGE NO.</u>
1	DESCENT VELOCITIES FOR VARIOUS STABILIZATION PARACHUTE CONFIGURATIONS - 2200 LB CARGO	76
2	EQUIVALENT CEP'S FOR VARIOUS AIRDROP CONFIGURATIONS	93
3	MEAN RADIAL ERROR FOR VARIOUS AIRDROP CONFIGURATIONS	93
4	SUMMARY OF ALTITUDE EFFECTS ON MISS DISTANCE . .	97
5	HLCADS - RECOMMENDED PARACHUTE CONFIGURATIONS. .	103

ABSTRACT

A study was conducted to identify feasible approaches for the airdrop of containerized cargo from aircraft flying at heights beyond the reach of certain types of ground fire. The primary application would be the resupply of combat units which, on occasion, may necessarily be within close proximity to hostile forces. Data was assembled and analyzed on the wind conditions that prevail in the airspace up to 15,000 feet above the drop zone. Concepts for equipment and techniques were generated and evaluated for their ability to guide the containers through this airspace and land safely in the limited area of a drop zone.

Aspects of the airdrop problem receiving particular attention were: effects of a varying airspace environment, navigation of the aircraft to the proper cargo release point, extraction of the cargos from the aircraft, parachute deployment methods, system stabilization requirements, and procedures employed in the terminal phase including initiation of this phase by a suitable height sensor. Response of the systems to airspace conditions was generated by computer from models that computed their total three-dimensional motion versus time. The performance of several designs are charted and plotted. Feasibility of achieving the desired airdrop accuracy is clearly indicated.

Recommendations for the preferred equipment configurations and airdrop procedures are included.

I. INTRODUCTION

This report is a summary of work performed on Contract DAAG17-72-C-0075, a study to identify feasible approaches for a High Level Container Airdrop System (HLCADS) and to evaluate analytically their merits in light of certain desired and required technical, operational, and economic criteria. The primary objective of the program was to specify the most feasible system(s) to deliver containerized cargo weighing from 200 to 2200 lb. from levels up to 10,000 feet above the terrain with a desired nominal accuracy of 200 meter diameter circle-of-equal-probability (CEP). The effort was concentrated on the detailed computer analysis of several concepts under actual wind conditions using AAI's Three-Dimensional Airdrop Program. Systems which were operationally suitable for rear-loading USAF cargo aircraft and had glide ratio of less than two were sought rather than those that required a guided high-performance gliding technique or major modification of the aircraft.

The study began with a review of the present Container Delivery System (CDS) in order to gain an appreciation of its advantages as well as its shortcomings for low and high level operation. In addition to reviewing the standard system, several extensions were investigated such as the Adverse Weather Aerial Delivery System (AWADS) and the High Altitude, Low Opening (HALO) resupply technique coupled with the Ground Radar Aerial Delivery System (GRADS). The information and understanding gained through this review was helpful in the formulation and analysis of concepts during the HLCADS study.

During the early phases of the program a search was undertaken to acquire as much data as possible on the wind conditions that prevail within the altitude range of the study. A set of unaltered wind profiles was found and from them a set of six were chosen which represented several extreme conditions. These profiles were used in the 3-D Airdrop program to determine the effects of winds on the accuracy of the various systems.

Extensive analysis of performance under various wind conditions has shown that high level airdrop systems can be developed using current state-of-the-art techniques that will achieve accuracies on the order of those desired. Results of these studies plus recommendations for the most feasible system are presented in detail in this report.

II. GOALS AND REQUIREMENTS

The purpose of the program was to formulate and analyze methods for the accurate delivery of containerized cargo from aircraft flying at heights beyond the reach of certain types of ground fire. The primary application of the system would be for the resupply of combat units which on occasion may necessarily be under close proximity to hostile forces. From the onset of the project, effort was guided by specific goals and requirements for the system and agreement was reached with the contracting agency as to which were desired goals and which were strict requirements. The following section summarizes the requirements and desired system characteristics which served as guidelines for concept formulation and analysis. Where an item was a strict requirement it is so designated.

1. The system shall deliver maximum accuracy with the nominal desired value being a 200 meter diameter circle-of-equal-probability for a single drop.
2. The drop zone shall have the most general possible characteristics concerning elevation, terrain, surroundings and nominally shall be a level area from zero to 5000 feet above mean sea level, surrounded by hills.
3. Minimum reliance shall be placed upon drop-zone-based devices and preferably no such device shall be used.
4. The location of the drop zone may be assumed to be known within ± 100 meters.
5. The maximum range of release altitudes should be from 2000 to 10,000 feet above the terrain.
6. The system should have the capability of releasing multiple loads from a single aircraft during a single pass over a given drop zone. Provisions for dropping from 1 to 16 loads should be included but multiple drop dispersion should be held to a minimum.
7. The system should permit concurrent airdrops from 1 to 36 aircraft.
8. The system should operate from rear loading cargo aircraft and permit the maximum possible range of aircraft velocities (nominally 130 to 150 knots IAS).

9. Although minor retrofit of the aircraft is permitted, modification of existing aircraft and reduction of their capacity or utilization should be avoided.
10. The system should be operational in the greatest possible range of climatic and weather conditions such as temperature, pressure, humidity and wind.
11. The system should require the minimum number of components and combinations thereof.
12. The system should make the maximum use of existing equipment and rigging procedures.
13. The system should deliver cargo units weighing up to 2200 pounds each with a nominal vertical velocity, at impact, of 30 feet per second for low-velocity drops and 90 feet per second for high-velocity drops. (This is a requirement.)
14. The desired maximum range of cargo weights that can be accommodated should be from 200 to 2200 pounds.

III. PROBLEM DISCUSSIONS

The high mobility of the modern army has created a need for rapid resupply in the field which can only be accomplished through airdrop procedures. Under most circumstances, highly successful results can be achieved using standard airdrop methods which are carried out at altitudes ranging from 600 to 1500 feet above ground level (AGL). Generally containerized loads of rations, ammunition, water, medical supplies, etc., weighing up to 2200 lbs. can be dropped into territory held by friendly troops with little difficulty using the standard Container Delivery System (CDS). However, when emergency resupply must be made to friendly troops near enemy-held positions, the exposure of the aircraft to ground fire becomes a serious consideration. In addition, if resupply is necessary for the support of clandestine operations in enemy territory, the procedure must be as acoustically, visually, and electromagnetically inconspicuous as possible.

In order to avoid ground fire during airdrop operations, it is necessary to drop from altitudes of 6000 - 10,000 ft. AGL. At these altitudes accuracy problems are compounded greatly for the standard CDS because the cargo remains under the influence of winds for an extended period of time. Complete wind profiles are usually unknown at the exact location and time of the drop so that large errors could negate the success of the resupply mission particularly in combat emergency or clandestine situations.

During the descent from high altitude, the cargo trajectory will be affected by horizontal wind shear layers of varying strength and direction. When the parachute cargo system enters a shear layer, it is subjected to an initial angle of attack and the subsequent motion is a combination of angular and lateral displacements. The magnitude of the displacement will depend on the shape of the load and canopy, the strength of the wind field, its gradient with respect to altitude, mass and apparent mass of the cargo and inflated canopy, and the cargo velocity. Nothing can be done to change the wind, but if some of the other factors concerning the cargo-parachute system could be controlled and the effects of the wind could be predicted with some degree of consistency, the accuracy of the container airdrop resupply operation could be improved.

One of the simplest ways to decrease the effect of the winds is to decrease the time in flight by increasing the descent velocity. When the parachute enters a wind layer, it tends to align itself with the relative wind and the greater the drop velocity with respect to the wind velocity, the closer the relative wind vector approaches the descent vector. Simple methods of increasing the descent velocity include delayed disreefing of the main recovery chute or staged deployment of a small canopy sufficient only to stabilize the cargo followed some time later by opening the main recovery parachute. Both methods were analyzed during the program and the results are discussed in detail in Section IV.

In addition to decreasing the effects of the wind on the cargo, accuracy can be improved by predicting the wind influence and locating the Computed Air Release Point (CARP) so that the cargo will impact on target. The wind profile between the ground and the aircraft changes constantly and in some cases may change direction and magnitude quite rapidly. The only wind data that can be measured with reasonable accuracy are the velocities at the ground and at the drop altitude. Anything between these extremes would be largely speculation and subject to frequent change. Methods for locating the target and predicting the proper Computed Air Release Point that have been tested and applied to container air delivery on an interim basis include "GRADS" (Ground Radar Air Delivery System) and AWADS (Adverse Weather Aerial Delivery System). Both methods were considered during the study.

In general, the overall solution to the container airdrop resupply mission under the conditions described in the Requirements Section involves the following considerations:

1. Dropping the cargo from an altitude sufficiently above danger from the hostile ground fire.
2. Predicting the effect of winds as well as possible without utilizing ground-based systems.
3. Locating and achieving the Computed Air Release Point which will achieve an on-target landing of the cargo after reacting to the winds.
4. Minimizing unpredictable reaction to winds by having the cargo traverse the airspace between the aircraft and the target in the minimum possible time consistent with the reliable functioning of system components and safe landing of the cargo.

These were the guidelines used in conducting the study. In addition the study was confined to decelerator systems having a glide ratio less than two. Gliding systems are being investigated in other programs so its exclusion here avoided dilution of the effort. The benefit of knowing ground wind conditions was included in the study. In some situations it would be possible to acquire and use this information, therefore, the anticipated effect it would have on system accuracy was evaluated.

IV. TECHNICAL INVESTIGATIONS

A. Study Methodology

1. General Method

The general goals of this program were to determine and examine analytically the feasibility and relative merits for various methods of accurately airdropping container loads from high altitudes in light of technical, operational, and economic considerations. The emphasis was on the analytical approach with the intention of determining which systems showed the most promise. Actual testing was beyond the scope of this study. A flight test plan designed to examine the merits of the recommended system experimentally was developed, however, and submitted as a part of the study.

The program began with an investigation of the current container air delivery system in order to establish a basis for problem identification and an understanding of its advantages and disadvantages within the bounds of the overall objectives and environment of this study. The various stages of the airdrop sequence (extraction, descent, recovery) were examined in order to define the problems and sources of error associated with each. The initial phase of the study was largely a team effort consisting of group discussions and brief study of available data. This preliminary study helped to identify certain procedures and factors associated with high-level air delivery that could cause difficulty in the successful completion of the mission as well as inaccuracy.

Having gained some insight into some potential problem areas, a detailed literature survey was made through the Defense Documentation Center, NASA, and other government and private agencies to determine as much as possible about the specific problem areas such as winds and wind predictions, parachute performance, aerodynamic characteristics of various cargo shapes and parachute configurations, and various experimental container airdrop techniques. Information was studied, consolidated, and analyzed by the various members of the project team. Throughout the study, new information from outside sources as well as feedback from internal analyses was used to revise and update the concepts under consideration.

Wherever possible, data collected through the literature search was used to formulate system concepts and establish the environmental and operational constraints of the study. If sufficient data for a specific consideration could not be found, separate analyses were carried out in order to establish the necessary or most desirable approach. These background studies and analyses of subsystems were used directly in the evaluation of general systems or required as input for the overall performance and accuracy analysis.

Data gathered through literature search as well as results of background studies and analyses were used as inputs to model the performance of airdrop systems under various environmental conditions. Aerodynamic characteristics of the cargo-parachute system and its reaction to varied wind and atmospheric conditions were related in a three-dimensional model and programmed for use on the CDC 6600 computer. As with other aspects of the study, new information from external sources in addition to feedback from internal analyses was used to modify and refine the computer model until it performed as complete and detailed an analysis as possible within the scope of the project.

In general the combination of literature research and mathematical analysis performed both manually and by the computer, coupled with frequent meetings and discussions of results allowed each member of the project team to contribute his special talent while receiving feedback from the others. Details of some of the background studies are discussed in this section.

2. Background Studies

a. Wind Conditions

In order to get an overall view of the vertical wind profile conditions, the first source consulted was the Handbook of Geophysics (1), which is necessarily a quite general reference. It indicated that winds at higher altitudes generally flow parallel to pressure isobars with the lower pressure being to the left of the direction of flow. Near the surface of the earth, frictional effects induce a component of flow across pressure isobars in a direction toward areas of lower pressure. The magnitude of this component is affected by the surface roughness characteristics of the terrain. Unfortunately, air flow caused only by the effects mentioned above exists only for conditions where there is no warm air advection; an ideal rarely achieved in reality. Thus, even though there are models for predicting wind profiles under text-book conditions, a great deal of difficulty is encountered when attempting to forecast conditions in the real world.

Further investigation led to the two large collectors of meteorological data, the U. S. Weather Service and NASA. Unfortunately the interests of these agencies do not coincide with the interests of this study. The Weather Service is primarily concerned with surface phenomena and most of their data are a result of measurements from towers 50-150 meters tall, far too low for altitudes of interest to this study (0 to 4.5 km). Typical of this data is the Airway Meteorological Atlas For the United States (2). On the other hand, NASA and some Department of Defense agencies have gathered considerable data for use in missile design and launching in the altitude range from 2 to 22 KM; which is too high for the interest of this study.

Another deficiency in the information of many sources is that generally they are averaged data, showing monthly, seasonal or yearly means. This averaging process wipes out the detailed variations and rapid changes in wind profiles that will effect a specific cargo airdrop.

What was needed then is a large body of unaltered wind soundings at one location, for altitudes of interest to the study. Fortunately one report by Scoggins and Susko (3) fulfilled much of this requirement and consists of a set of 112 cases of raw wind soundings at 25 meter intervals conducted over a period of about eight months. A deficiency of the data is that the altitude of the lowest sensing is 150-300 meters in most cases. However, a report by Talley (4) consisting of wind velocities measured at 100 ft. increments on a 1200 ft. tall tower showed that, while wind speed and direction changed greatly as a function of time, winds of significant magnitude remained relatively uniform in the altitude range of 0-250 m at any specific instant of time. Thus, in accordance with the assumption that all cargos from a single aircraft occupy the same airspace at the same time, the lowest altitude wind sensing could be used to ground level in the computer model.

Using all 112 data cases in the computer simulation would have been prohibitively expensive, so the cases were edited to provide a more meaningful smaller set of data. The first step was to eliminate data cases where the initial sensing occurred above 250 meters. This decreased the number of the cases to 48. Further, data cases with lowest altitude sensings greater than 15 knots were eliminated, resulting in 18 cases which are shown graphically in Figures 1, 2 and 3. From this group, eight cases were selected which included those cases with the greatest variation in both wind direction and magnitude between 10,000 feet Above Ground Level (AGL) and the surface. This set consists of Cases 32, 42, 50, 75, 77, 78, 83, and 87 designated in the figures. Plots showing the complete profile for these cases are included in Figures 4, 5, 6, 7, 8, 9, 10 and 11. The winds in these figures are defined as follows: (1) Ground wind - the direction and magnitude of the wind at the drop zone, (2) Altitude wind - the direction and magnitude of the wind at the aircraft altitude, (3) Resultant wind - the vectorial sum of the wind vectors at each data altitude divided by the number of data points, and (4) Ground - altitude wind - the vectorial sum of the ground and altitude winds divided by two.

The literature search showed that there can be large changes in wind vector as a function of altitude, ground location, and time. However, during the course of an airdrop operation, the cargos occupy a relatively small airspace measuring approximately one mile long x 1/2 mile wide x two miles high for a reasonably short period of time (on the order of one minute). For this reason, the wind variation as a function of ground position and time was neglected and the magnitude and direction at any given altitude was assumed to be constant for the duration of the drop. Also the literature study showed that the vertical component of the wind vector would be negligible in relation to the horizontal components so for simplification the vertical component was assumed to be zero. Thus, the total air space relevant to the drop operations was considered to be composed of layers of air moving at constant velocity with the magnitude and direction varying only as a function of altitude. For use in the computer model, the wind vector is expressed in terms of its horizontal components at discrete altitudes and to avoid discontinuities, the model assumes linear gradients between altitude data points for both magnitude and direction.

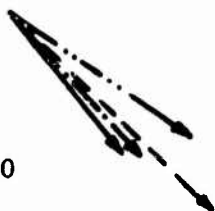
CASE 78



CASE 103



CASE 80



CASE 75



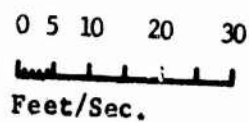
CASE 22



CASE 87



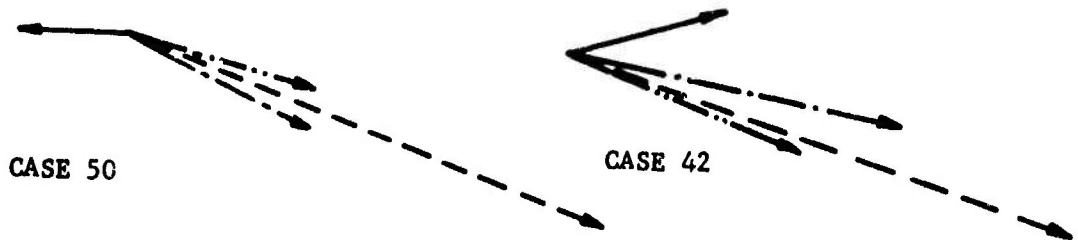
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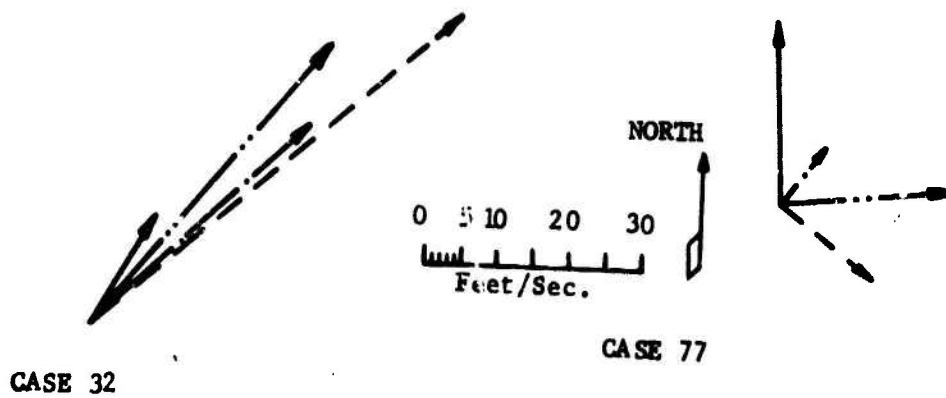
—————	Ground Wind
-----	Altitude Wind
.....	Ground & Altitude Wind
.....	Resultant Wind

WIND VECTORS
FIGURE 1



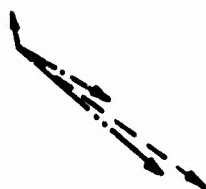
KEY

—————	Ground Wind
-----	Altitude Wind
.....	Ground & Altitude Wind
.....	Resultant Wind



WIND VECTORS CONTINUED
FIGURE 2

CASE 82



CASE 76



CASE 60



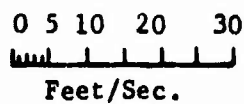
CASE 88



KEY

<u>————</u>	Ground Wind
<u>-----</u>	Altitude Wind
<u>.....</u>	Ground & Altitude Wind
<u>.....</u>	Resultant Wind

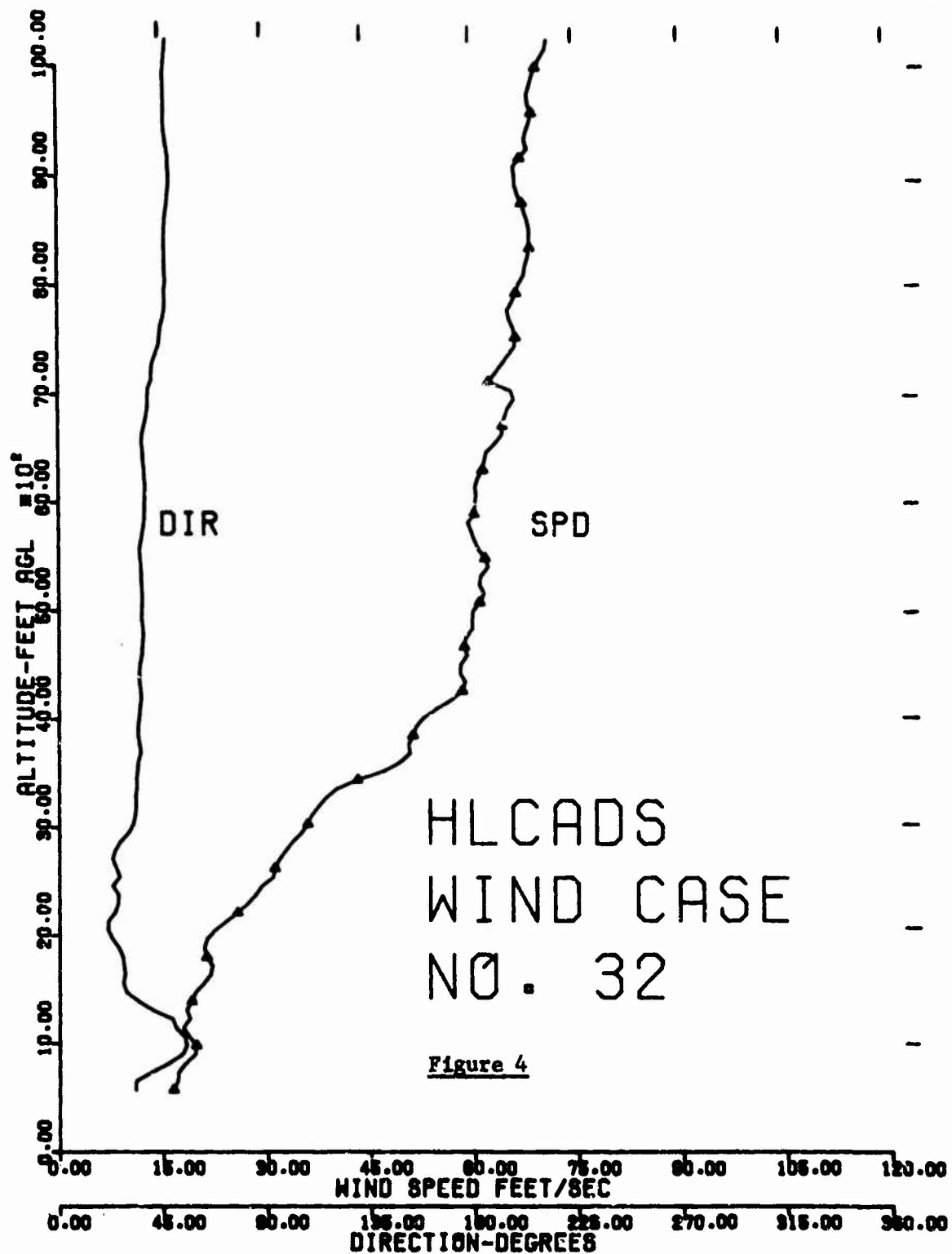
CASE 64

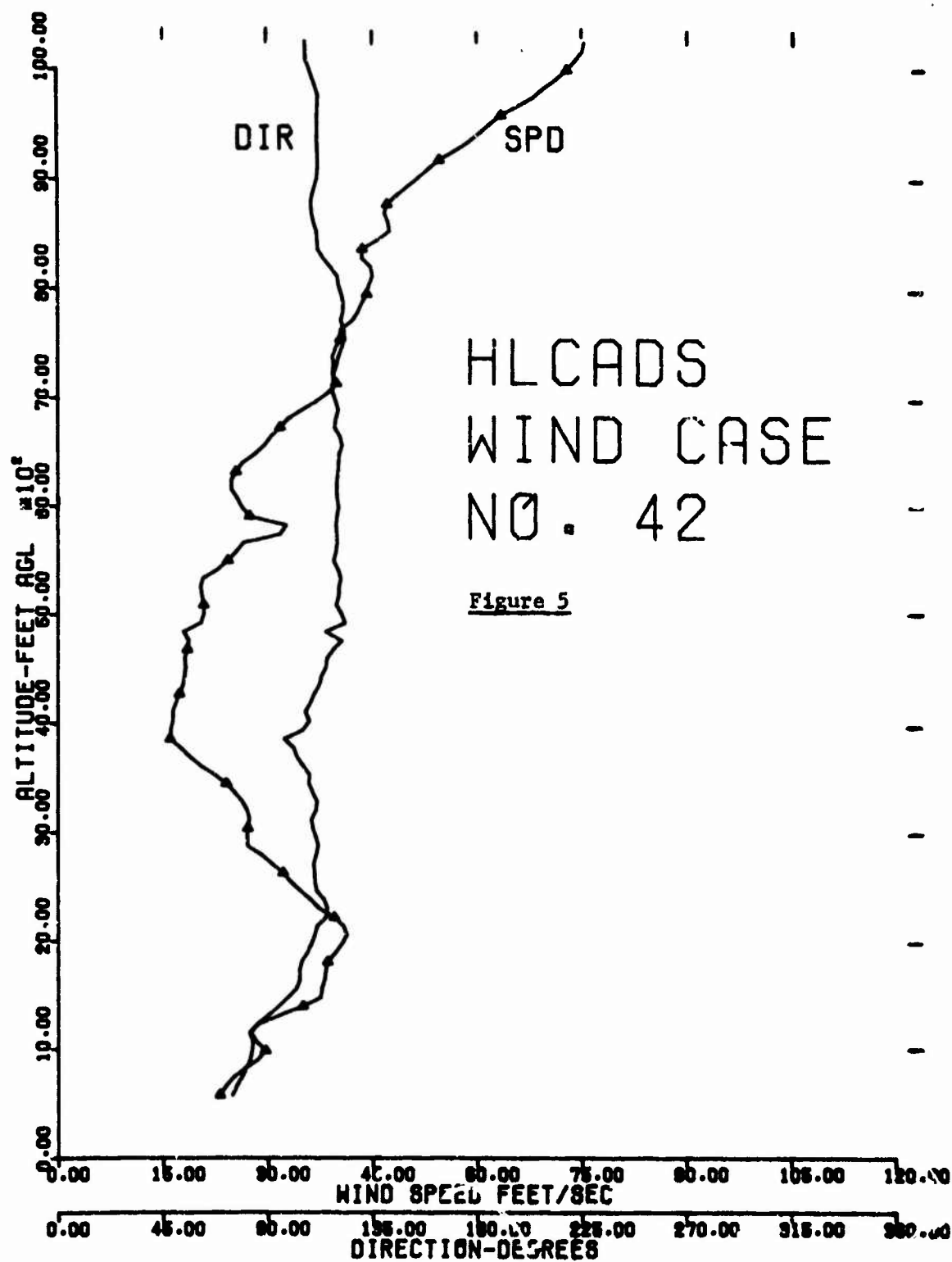


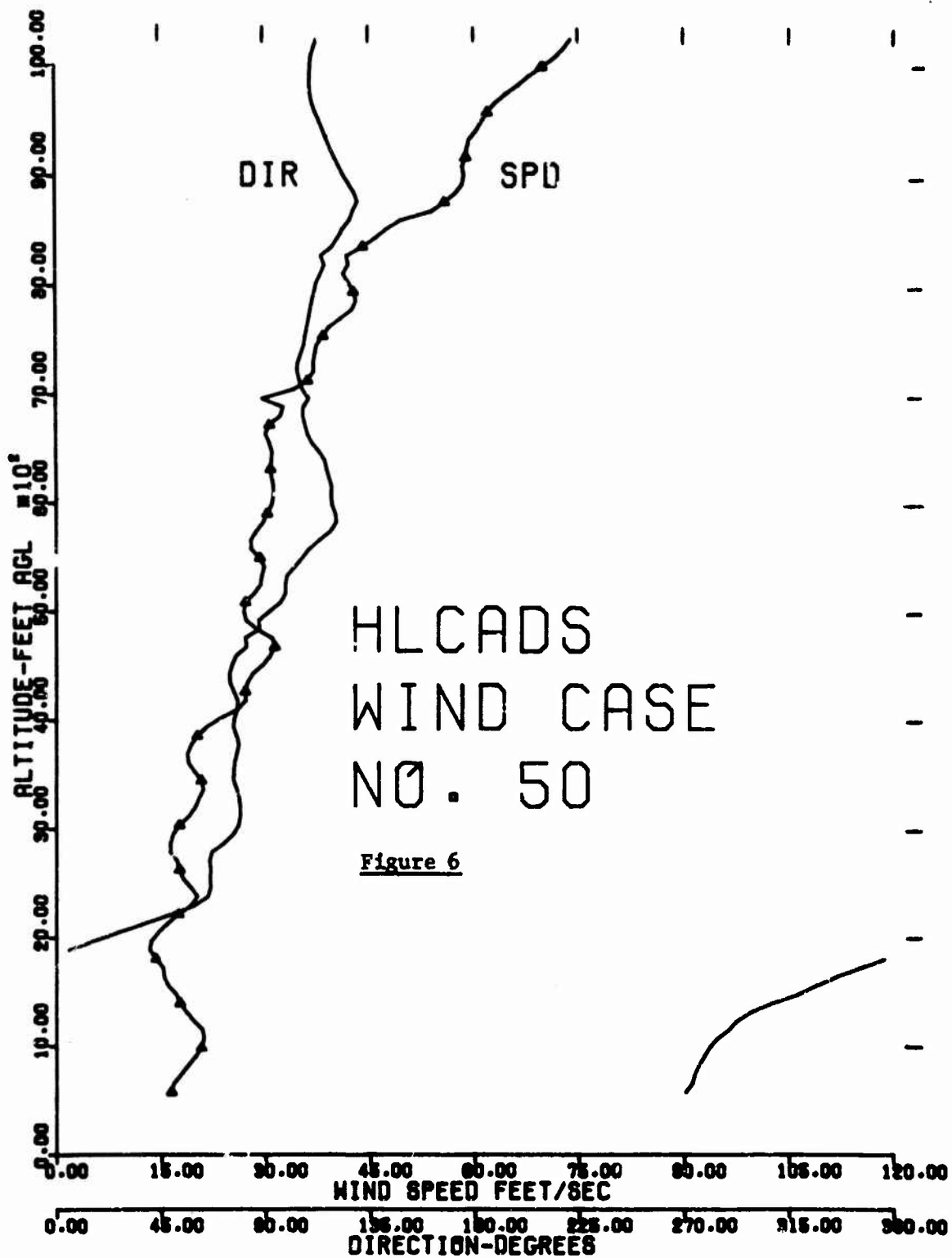
CASE 23

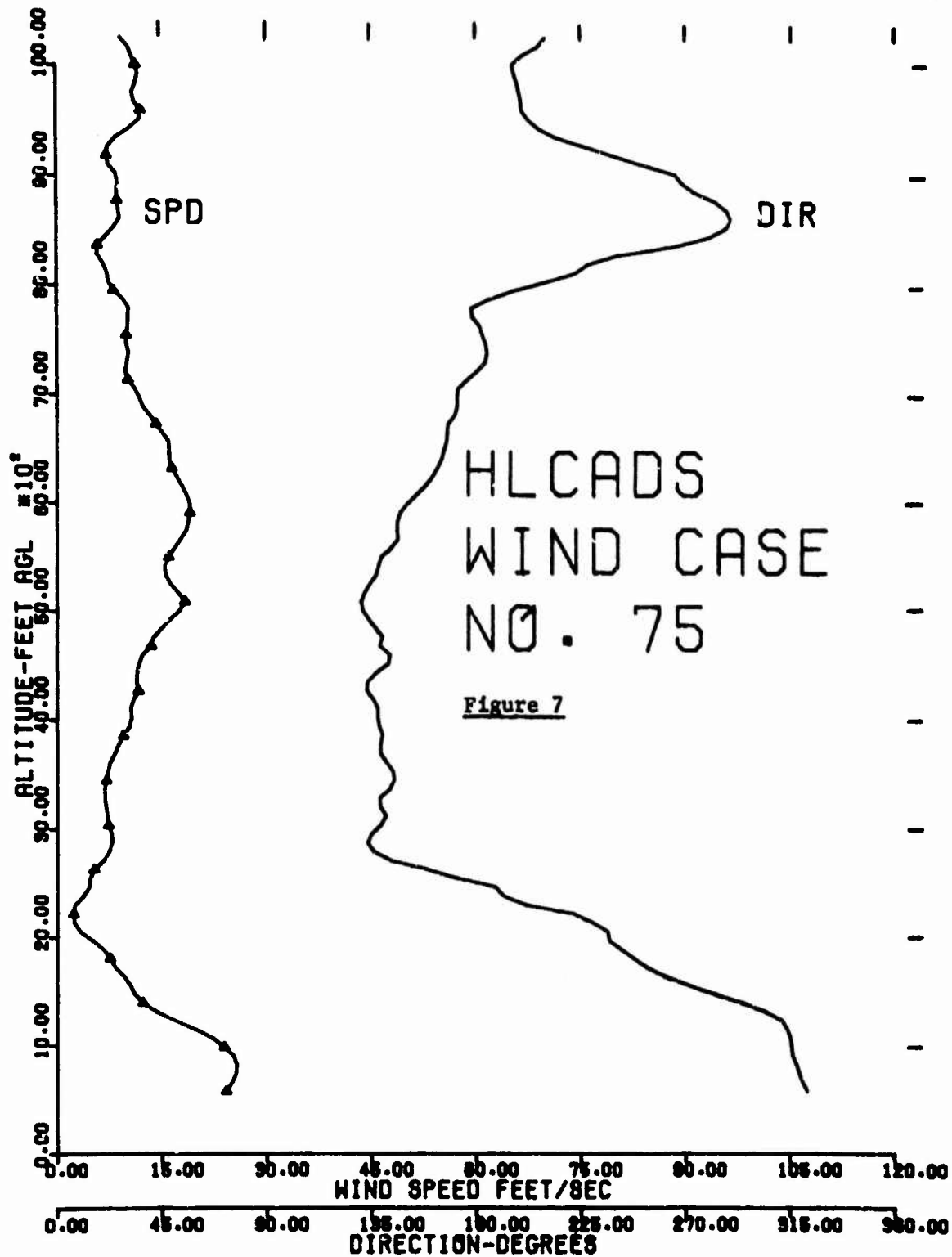


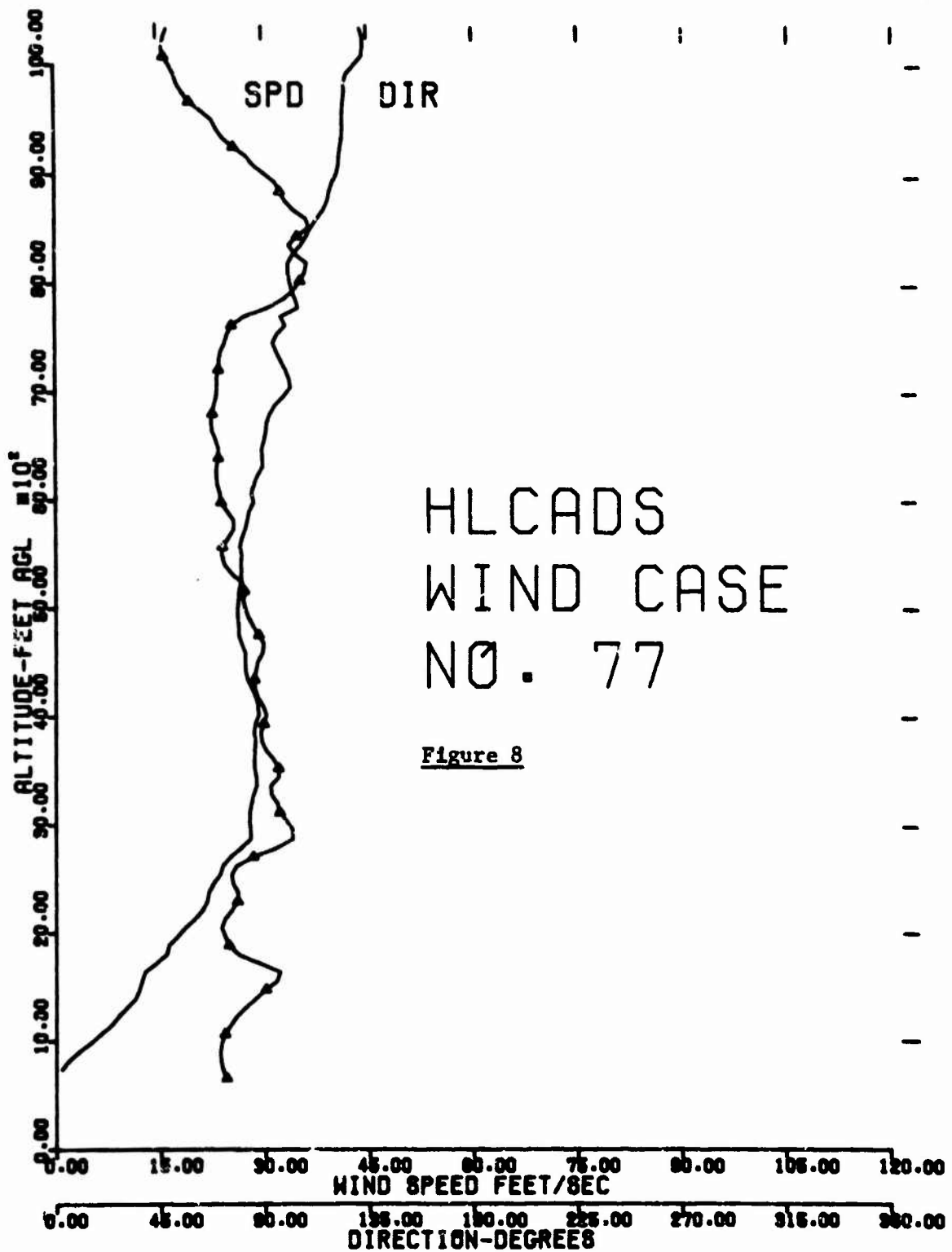
WIND VECTORS CONTINUED
FIGURE 3

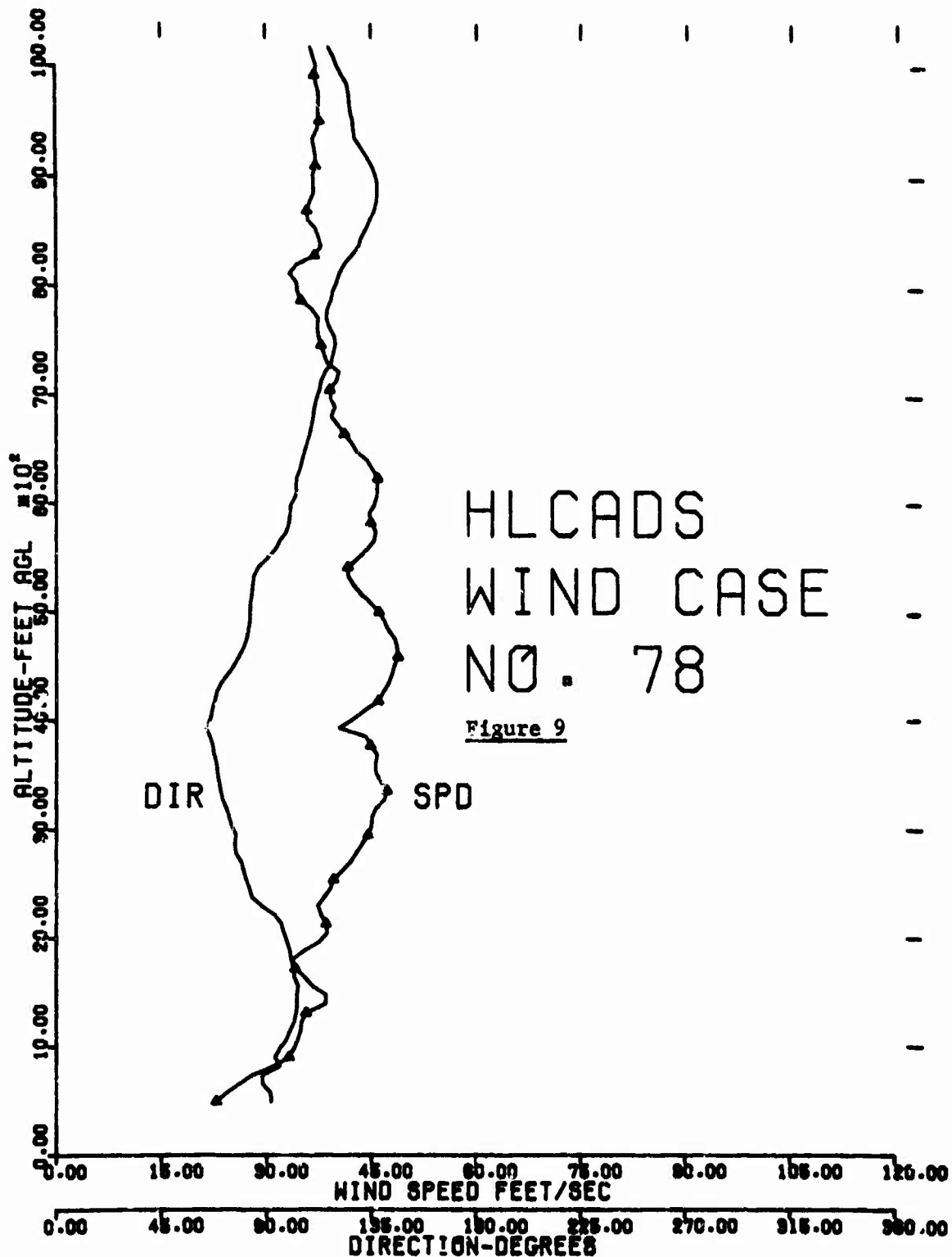


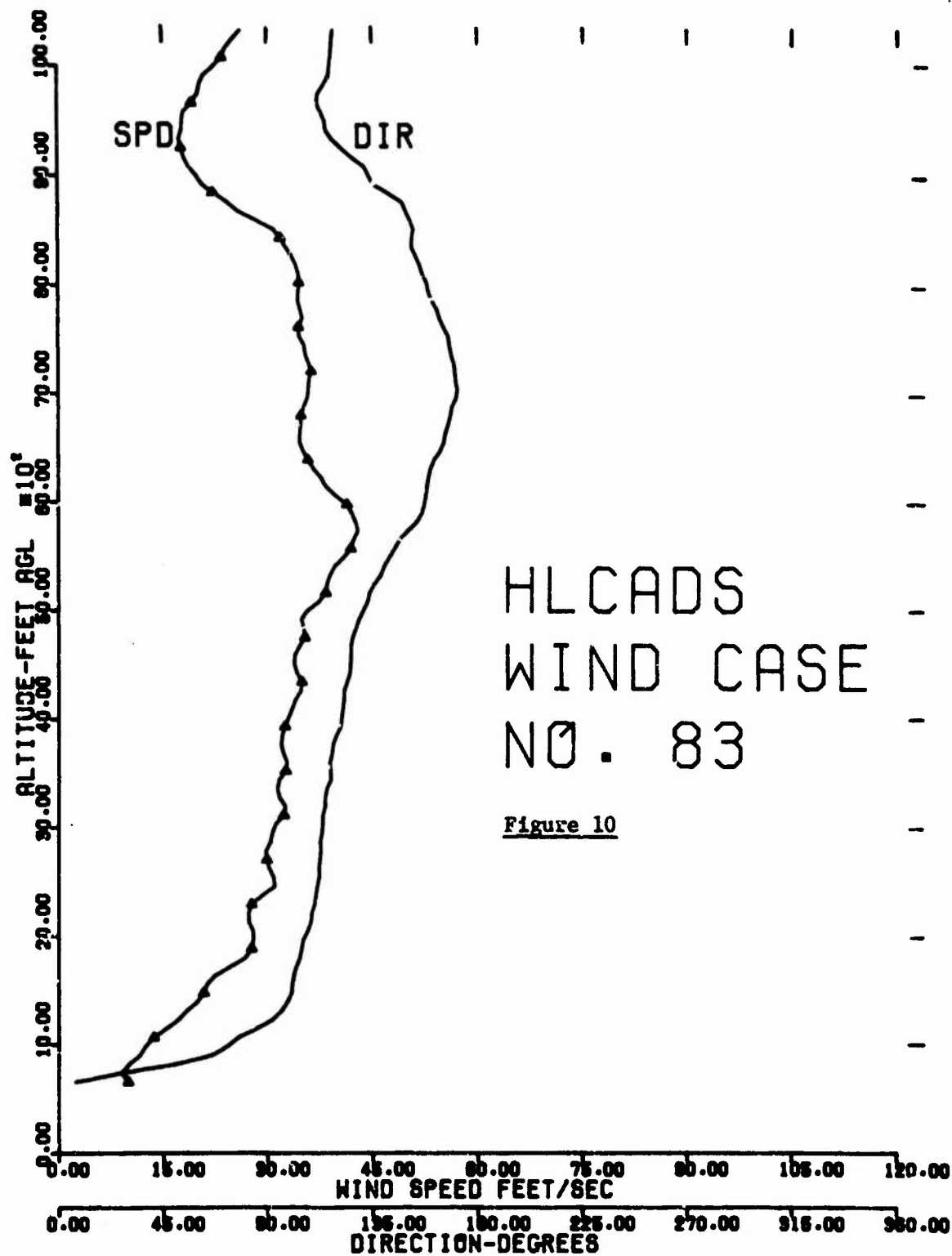


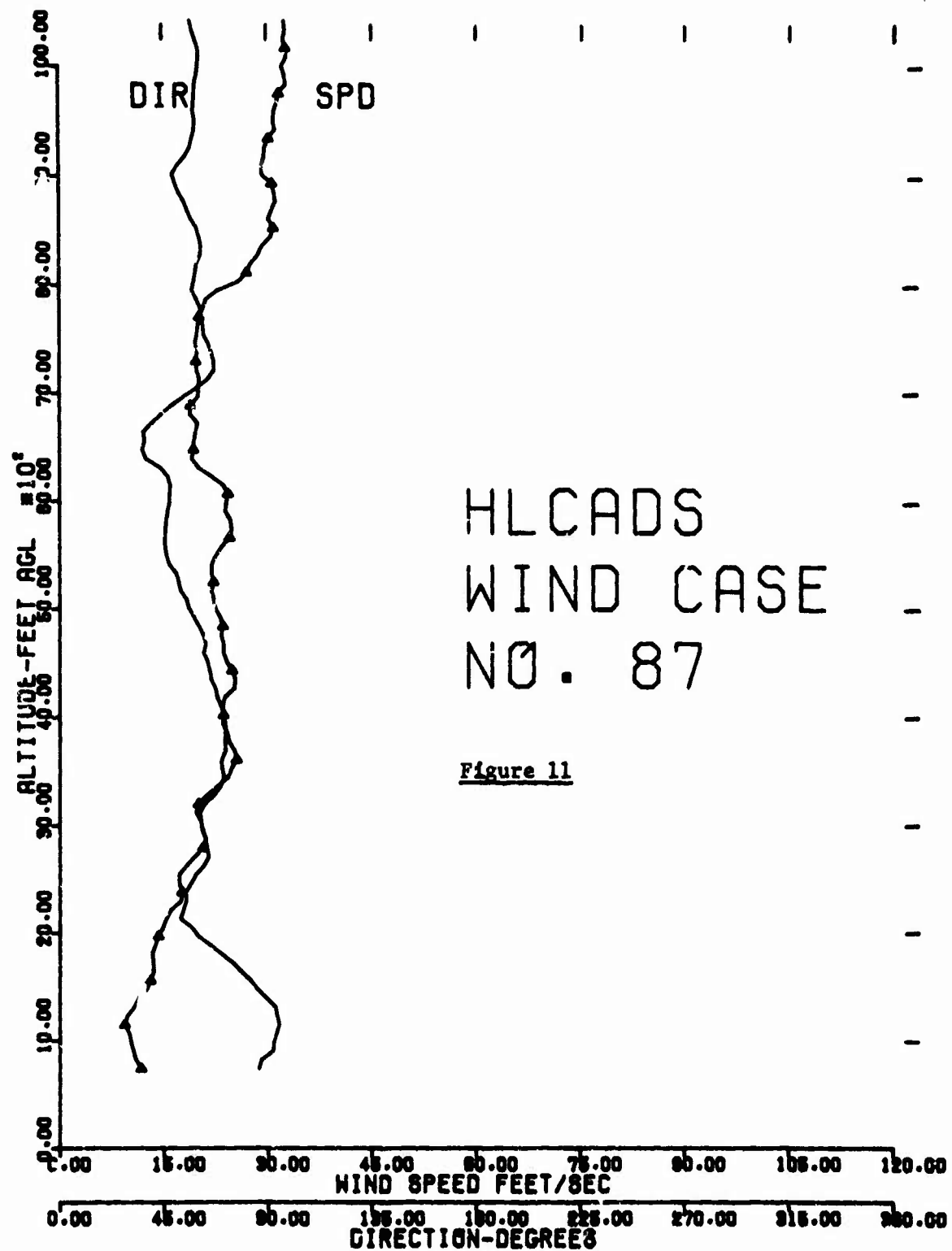












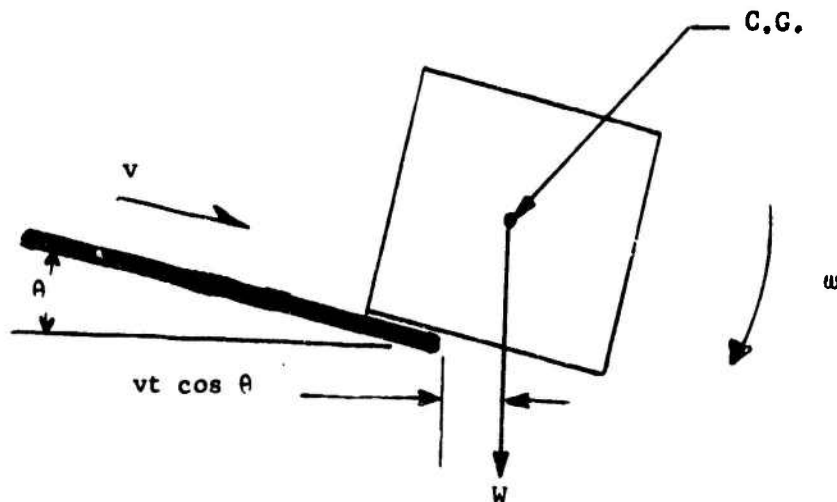
b. Cargo Stabilization Study

One technique for decreasing the influence of unpredictable winds in the airspace between the release point and the target is to allow the cargo to descend as rapidly as possible. However, in order for the cargo to follow a predictable trajectory the overall aerodynamic configuration must be stable. Thus, a parachute or similar drag device that is large enough to prevent the container from tumbling must be used throughout the descent. Ideally, the parachute should supply only enough drag to stabilize the container and not retard its descent more than necessary to insure a safe recovery.

For the trajectory of the container to be predictable and repeatable the system must be both dynamically and statically stable. That is, the parachute should be large enough to stop the container from tumbling after tipoff as well as prevent it from tumbling during descent. The minimum size parachute for satisfying both criteria was determined by examining wind tunnel tests of the containers under consideration and performing an analysis of the tipoff phase of the standard container delivery system.

A review of wind tunnel tests and accounts of previous experience with flow around parallelepiped bodies indicated that unstabilized three dimensional motion (the condition immediately after the container leaves the aircraft) could be extremely complex and difficult to predict. To conserve time a two dimensional analysis was undertaken. It was felt that this procedure would give a reasonable approximation and events later proved that the results agreed, reasonably well, with wind tunnel test data for containerized cargo. Several assumptions were made concerning the shape of the container and the extraction phase of the container airdrop. The cargo was considered to be a homogeneous cube 52 inches on the side with its c.g. located at the geometric center and it was assumed that the containers were allowed to roll out of the aircraft with the aircraft pitched up at a 6° deck angle. Furthermore, it was assumed that in order to avoid any danger of tangling riser extensions or suspension lines, the angular velocity of the container must be stopped before it rotates 180° with respect to the horizontal.

In order to stop tumbling when using the standard container delivery system, the restoring torque supplied by the parachute must be large enough to arrest the angular velocity caused by tipoff. The angular acceleration during tipoff results from the weight of the cargo acting through a moment arm from the cargo c.g. to the edge of the ramp and is illustrated in the following sketch.



If the exit velocity were constant, the angular acceleration at any time would be

$$\alpha = \frac{W v t \cos \theta}{I} \quad (1)$$

where:

α = angular acceleration (rad/sec²)

v = velocity along the ramp (fps)

t = time after c.g. passes edge of ramp (sec)

θ = angle of deck

I = moment of inertia (ft-lb-sec²)

If the exit velocity is changing, the angular acceleration may be computed on a step by step basis for small time increments until the cargo leaves the ramp.

For the purpose of the analysis it was assumed that deployment of the stabilization chute would begin as the c.g. of the cargo passed the edge of the ramp. Also it was assumed that deployment and filling time for the stabilization parachute would be approximately 0.5 second and that there would be no restoring torque applied to the cargo until the parachute was fully inflated.

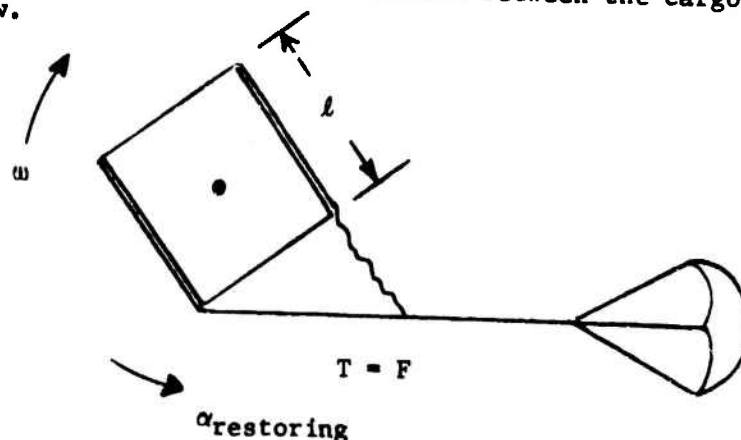
Once the cargo leaves the aircraft, it will continue to tumble at a constant angular velocity until the stabilization parachute can stop it within the maximum allowable rotation. Letting ψ denote the angle of rotation, the allowable time to stop the tipoff tumble is:

$$t_{\text{allowable}} = \frac{\psi_{\text{max}} - \psi_{\text{tipoff}}}{\omega_{\text{tipoff}}} \quad (2)$$

and the restoring angular acceleration that must be supplied is,

$$\alpha_{\text{restoring}} = \frac{\omega_{\text{tipoff}}}{t_{\text{allowable}}} \quad (3)$$

It was assumed that within the total angle of rotation of the container the average moment arm through which the restoring torque is delivered is equal to one half of the side of the container and that the restoring force is equal to the line tension between the cargo and parachute as shown below.



about the c.g. is

In this case the force that is required to stop rotation

$$F = \frac{2 I \alpha_{\text{restoring}}}{l} \quad (4)$$

and the area of the required parachute is

$$A = \frac{2 F}{C_D \rho v^2} \quad (5)$$

where:

C_D = drag coefficient based on the relevant area

ρ = air density adjusted for altitude (slugs/ft³)

V = velocity with respect to air (fps)

Assuming an effective coefficient of friction between the cargo and ramp of $\mu = .02$, the acceleration along the ramp is

$$\begin{aligned} a &= g[\sin 6^\circ - .02 \cos 6^\circ] \\ &= 2.75 \text{ ft/sec}^2 \end{aligned}$$

If the ramp is 10 ft. long, the velocity of the cargo when the leading edge reaches the edge of the ramp is 7.41 fps. Considering a 2200 lb. load and solving on a step-by-step basis with equation (1), the cargo leaves the ramp .25 seconds after the c.g. passes the edge with a linear velocity of 9.00 fps, an angular velocity of 2.70 rad/sec and an initial angle of 19.5 degrees. The stabilization parachute inflates after the cargo rotates an additional 38.7 degrees so that the total rotation before restoring torque is applied is 58.2 degrees (1.02 radians). From equations (2) and (3), the time available to stop the rotation short of 180 degrees is .78 seconds and the required angular deceleration is 3.46 rad/sec². Using equation (4) where $I = 214 \text{ ft-lb-sec}^2$ and $l = 52 \text{ in.}$, the restoring force is,

$$F = \frac{2(214)(3.46)(12)}{52} = 342 \text{ lb.}$$

At an altitude of 10,000 ft, $\rho = .00167 \text{ slugs/ft}^3$ and an indicated air speed of 130 knots is 250 fps with respect to the ground. The drag coefficient for a ring slot parachute is .55 based on the constructed area. Substituting in (5),

$$A_{\text{ring slot}} = \frac{(342)(2)}{(.55)(.00167)(250)^2} = 11.9 \text{ ft}^2$$

and the constructed diameter is 3.9 ft.

Wind tunnel tests by Heinrich and Ibrahim⁽⁵⁾ showed that an A-22 container could be stabilized over a full angular range by using 10 ft. long risers and a 4 ft. diameter ribless guide surface canopy or 5.3 ft. diameter ring slot, ribbon or flat circular parachutes. It can be seen that the results of the simplified analysis agree reasonably well with the wind tunnel data and that the experimental results are slightly more conservative than those computed. Because the tipoff analysis did not consider the airflow around the container and because the wind tunnel data represented actual test results most of the computer analysis of systems using independent stabilizing canopies used configurations recommended in the Heinrich report.

Reefing the main recovery parachute as a means of increasing the rate of descent was also considered. A report by Claunch⁽⁶⁾ showed that a G12-D cargo chute reefed to 3.76 ft. diameter or a 28 ft. ring-slot chute reefed to 4.6 ft. diameter could be used successfully to stabilize a 2000 lb. container cargo. They were disreefed as they approached the drop zone, the G-12D providing a low velocity recovery and the 28 ft. ring slot a high velocity impact. This technique was evaluated during the study and compared to other methods.

Computer analyses revealed that cargos equipped with the minimum required stabilization parachute configurations achieved descent velocities in excess of the maximum allowed for predictable opening of the G-12D main recovery parachute. In order to confine the cargo's rate of descent to a level compatible with reliable opening of the recovery parachute larger stabilization parachutes were investigated. It is possible that other recovery parachutes would function at the high velocity but performance data for these parachutes was not available during the analysis phase of the program. Thus, it was determined that the critical consideration in designing the most desirable decelerator configuration was not cargo stability but rate of descent during the high velocity phase of the trajectory. Results of the analysis and a discussion of the final configuration are presented in Section IV-C-4.

c. Extraction Study

A number of possible extraction methods were examined during the study. The following is a list of methods considered:

- (1) Mechanical conveyance or winching
- (2) Chemical thrust devices - rockets
- (3) Attachment to another aircraft
- (4) Vertical release - "bombing"
- (5) Extraction parachute
- (6) Gravity roll-out

These methods were subjected to a preliminary study to determine advantages and disadvantages, feasibility, and suitability to the requirements of the study.

Mechanical conveyance systems for expelling airdrop cargo were found to require large amounts of power. Also it is difficult to attach the expulsion device to the airframe without major modification to the aircraft. These deficiencies were judged sufficient to eliminate this method from further study.

The second method, chemical thrust devices, overcomes some of the deficiencies of the first method because there are no requirements for attachment to the airframe and large amounts of power are compactly available. However, there are several disadvantages to the system. First, there is the problem of getting the devices positioned so that they can be operated without damaging the aircraft and the cargo. In addition, the device must be sized to fit the particular cargo mass. Once the cargos leave the aircraft, the descent and recovery phases would be the same as that for any other extraction technique. Because of the inherent danger associated with such systems being used inside the aircraft, it was decided that further study of the system was unwarranted.

Another method that had been studied by White et al., (7) is that of extraction by attachment of the cargo to another aircraft. In theory, the second aircraft simply slows down and extracts all the cargos as a single compact unit. However, in practice there are many complications and disadvantages of the system including the need for aircrews trained specially in precision flying techniques. Extensive aircraft modification is also required. In addition, the precision flying requirements would restrict the system so that it would be workable only under the best conditions of weather, lighting, and enemy counter-action. All in all, it was concluded that the method was not feasible for this application.

A vertical release method similar to dropping bombs is also a possibility but would require extensive modification of cargo aircraft, or in the extreme case, the use of bombers themselves. Since the

system is to be applicable to current and future cargo aircraft, this method was discarded.

The possibility of using an extraction parachute to pull containers or groups of cargos from the aircraft received considerable attention. This method is currently used to airdrop large platform loads so there is currently a variety of usable hardware in inventory. Aircraft control is easy because the flight attitude at cargo release is straight and level, and since current cargo aircraft are already equipped for use of extraction parachutes, aircraft modification would be minimal. There would be some problems associated with distributing the extraction force to the individual cargos and sizing the parachute(s) for various weights.

The current container delivery system of extracting the cargos by allowing them to roll out of the aircraft under the influence of gravity was studied extensively because of its inherent simplicity. There is no need to make adjustments for cargo variations or cargo mass nor is there any need for aircraft modification. The technique is not, however, without problems, particularly the difficulty in maintaining the nose up attitude of the aircraft caused by the shifting of the cargo load. As the cargo moves toward the rear exit, the center of gravity of the load and therefore of the aircraft, shifts rearward and then forward again as the load leaves the aircraft.

Extraction by parachute and gravity drop as currently practiced appeared to have more potential than the other methods and were analyzed in detail. The following is a review of these analyses.

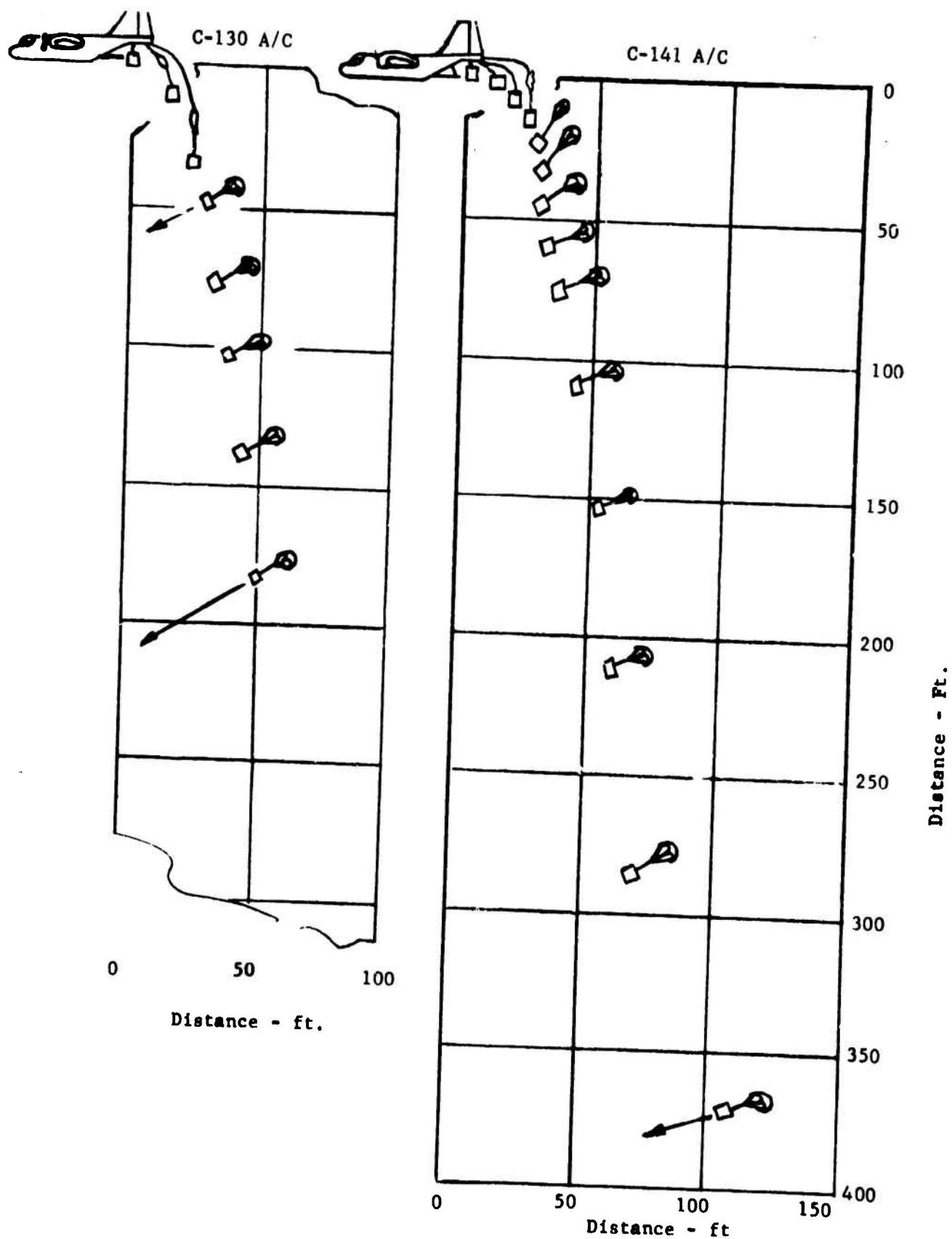
Since gravity extraction is used in the current container airdrop practice, it was studied first as a guide for state-of-the-art. Various U. S. Army and Air Force manuals were studied for familiarization with the procedures. A web or net-type "gate" is secured to the airframe behind the aft-most cargo. As the drop zone is approached, the cargo doors are opened, the ramp is lowered to the level position, and the aircraft assumes an approximately 6° nose up attitude by a combination of flap settings and manual control. Upon reaching the release point, a small extraction parachute which is attached to cutting knives on the cargo-restraint gate is dropped from the aircraft. When the parachute opens, it cuts away the restraint gate, allowing the cargos to roll out on the roller conveyor system from an acceleration induced by gravity which at the 6° pitch is about .09g. For the C-130 aircraft this means that the first cargo container clears the ramp edge after 2.7 seconds and 8th or last pair of containers exit 6.1 seconds after release of the gate. Elapsed time from first to last is 3.4 seconds. Recent experiments reported by Monson (12) indicate that delivery accuracy can be significantly improved by using explosive operated cutters to open the restraining gate rather than rely on the extraction parachute method described above. The explosive operated cutter responds immediately

to a signal, thus, eliminating the variability in a number of sequential events associated with the parachute method. Future consideration of the gravity extraction method should include the possibility of using this apparent improvement in the procedure.

For the analysis of extraction by parachute it was assumed that the process would follow a scheme similar to that of large platform loads. This scheme would require that a secondary system be adopted for restraining the containers or groups of containers and would proceed as follows: While in the aircraft, the cargo is restrained from moving fore and aft by primary restraints. Before reaching the release point, the primary restraints are released and the doors are opened. At the release point the extraction parachute is released from the aircraft carrying with it a line which is connected to the first cargo. The extraction parachute inflates, generating a force that overcomes the secondary restraints and pulls the cargo from the aircraft. As the first cargo exits, it carries with it the extraction parachute for the next cargo. The process continues until each cargo or group of cargos has exited. Analysis showed that the exit time for the entire load is dependent upon the number of container groups that must be extracted because of the time required for each successive extraction parachute to inflate and pull the containers from the aircraft. If standard inventory parachutes are used and extraction forces are maintained at or below 1.5 g's, calculations show that all of the containers must be grouped in no more than two individual bunches in order for the extraction time to be less than that for the gravity extraction technique used with the standard container airdrop system.

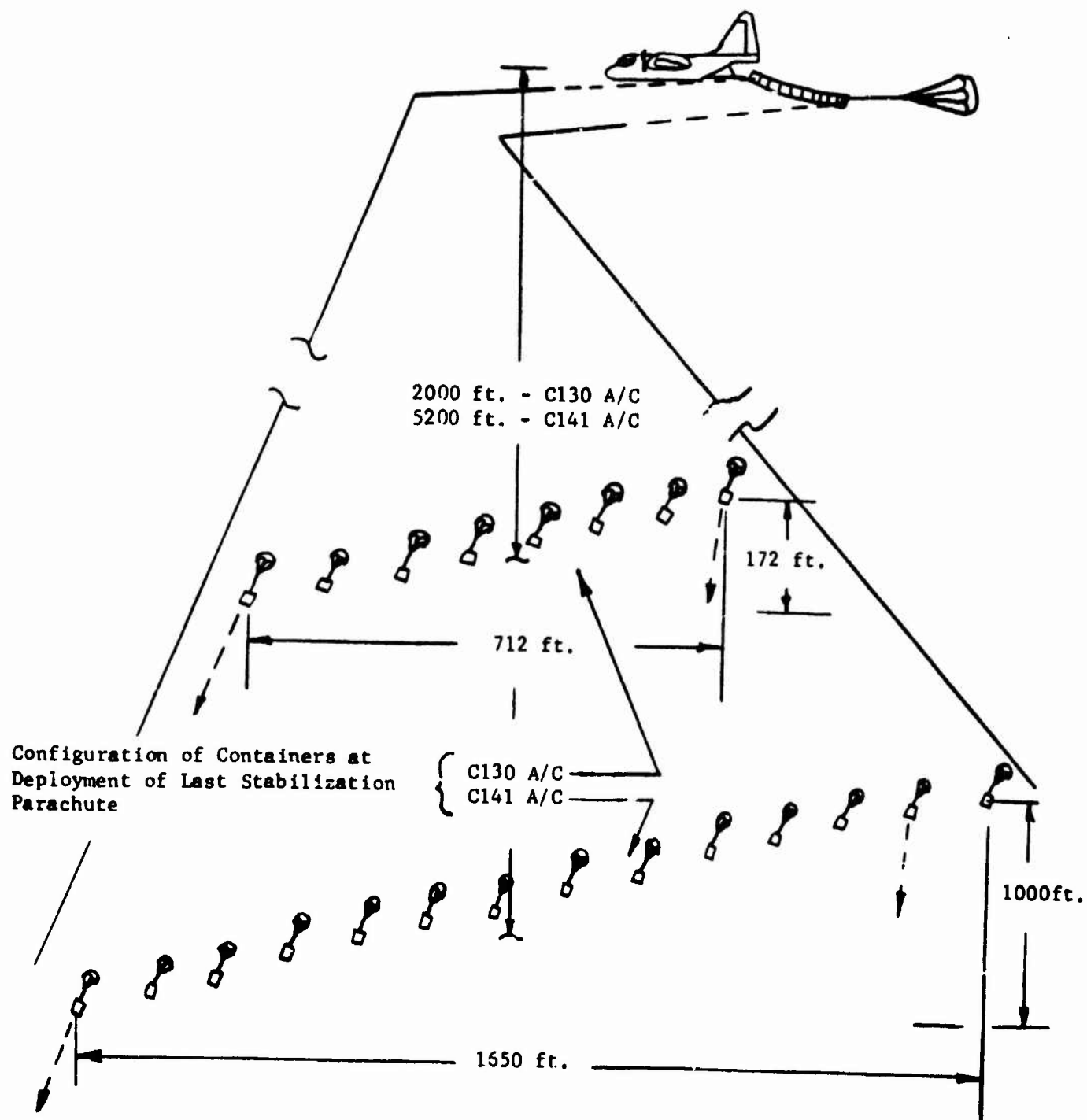
The rationale behind the extraction study was that faster cargo exit would result in closer grouping at the release altitude and hence, tighter groups on the ground. However, speed of exit is not the entire story. The configuration of the load at the time of deployment of the stabilization device is also important because it delineates the manner in which this device is deployed. Figures 12 and 13 show the configurations of the loads as the last cargo clears the ramp for gravity and parachute extraction respectively from the C-130 and C-141 aircraft.

Figure 12 shows that containers which roll out of the aircraft under the influence of gravity assume a nearly vertical pattern because the first cargos out have a lower velocity relative to the aircraft than those that exit last. This means that the first cargos to exit the aircraft have a higher forward velocity relative to the ground than the last so that the first cargos out tend to "catch up" with later cargos, thereby shortening the horizontal spread of the pattern. Also, the containers are arrayed vertically while their velocity is still nearly horizontal. Thus, the stabilization parachutes will stream back in a direction opposite the velocity of the containers and nearly normal to the line of the group eliminating interference between the individual parachutes.



GRAVITY EXTRACTION - C130 AND C141 AIRCRAFT

Figure 12



PARACHUTE EXTRACTION - C130 AND C141 AIRCRAFT
Figure 13

Study of Figure 13 shows that the containers in this system are arrayed in a very tight group with all units at nearly the same altitude. This configuration would give good grouping on the ground if all stabilization parachutes could be deployed at that time. However, the group is arrayed in a pattern generally parallel to their direction of motion. This means that in order to avoid interference the stabilization parachutes must be deployed in sequence with the aft-most cargo first with a delay before the next parachute deploys so that the first cargo is pulled clear of the second parachute. This causes the group to spread out over a considerable distance and the apparent advantage of group extraction is lost. The spread of the containers as the last stabilization parachute is deployed also is illustrated in Figure 13. Also, the apparatus needed to achieve the necessary sequencing of container release and deployment of the stabilization parachutes would require extra equipment and rigging time as compared to the gravity extraction system which can employ a standard technique of static lines to deploy the stabilization parachutes.

System performance using gravity extraction was analyzed for both the C-130 and C-141 aircraft and total spreads of the load at the drop zone under no-wind conditions were computed to be 753 and 1177 feet, respectively. (See Section IV-C-1-a). This difference in spread is due to the number of containers that each aircraft is capable of carrying. The C-130 airplane can carry 16 containers arranged in two rows of 8 each, whereas, the C-141 airplane can accommodate 28 containers in two rows of 14 each. These spreads are considered acceptable. Using the parachute deployment scheme described above, group extraction results in an increased spread of the load at the drop zone. Unless a better scheme is developed for deploying the stabilization parachutes in the group extraction method, gravity extraction is the better of the two approaches and is recommended for use on both the C-130 and C-141 aircraft.

3. Computer Model

The bulk of the performance analysis for this program was accomplished using modifications of airdrop programs written for various similar airdrop projects and run on the CDC 6600 computer. The program used to analyze airdrop accuracy is a three dimensional trajectory model which is capable of considering the effects of three dimensional wind vectors that vary in magnitude and direction as a function of altitude. Parachute diameters and inflation characteristics are assumed known a priori and are handled as inputs to the model. In addition to any desired wind profile, the physical, geometric, and aerodynamic characteristics of the cargo and parachute, as well as the release conditions are read into the computer. The model automatically considers the effect of the apparent air mass of the parachute and the variation in air density as a function of altitude. The output from the program is given as a function of time and consists of the distance traveled, velocity and acceleration of the cargo for each coordinate with respect to a ground fixed origin as well as the parachute position in the same coordinate system and the line tension between the parachute and cargo.

At the beginning of the project some simplifications were introduced into the mathematical model's treatment of aerodynamic forces on the cargo. This was necessary due to the absence of detailed aerodynamic data for the A-22 container but it was believed that the errors would be small because of the nearly cubical shape of the container. The simplification consisted of treating the cargo as a point mass on which the only aerodynamic force acting was drag. Later in the project aerodynamic information for the A-22 container derived from wind tunnel studies was obtained permitting more sophisticated modeling and a comparative analysis of the two approaches was undertaken using a two dimensional program modification. The results showed that there was less than 1% variation between the trajectories of the two models. Because the difference was insignificant, it was decided to continue using the simplified model rather than spend considerable time and effort for a complete three-dimensional modification of the computer program.

The two techniques that were used to describe the descent phase of the airdrop study are discussed below. Program #1 is the model which was used for most of the trajectory analyses and basically treats the cargo and parachute as point masses. As such, the cargo does not rotate and the only aerodynamic force acting on the cargo is a drag force in the direction opposite to the air speed vector. Program #2 is a two-dimensional modification of Program #1 which allows the cargo to rotate about its pitch axis and accounts for lift force and an aerodynamic restoring moment as well as drag.

Program #1

This program assumes the following:

1. The cargo and parachute are treated as point masses
2. The cargo drag force vector is always in the opposite direction of the air speed vector.
3. The parachute drag force vector is always in the opposite direction of the air speed vector.

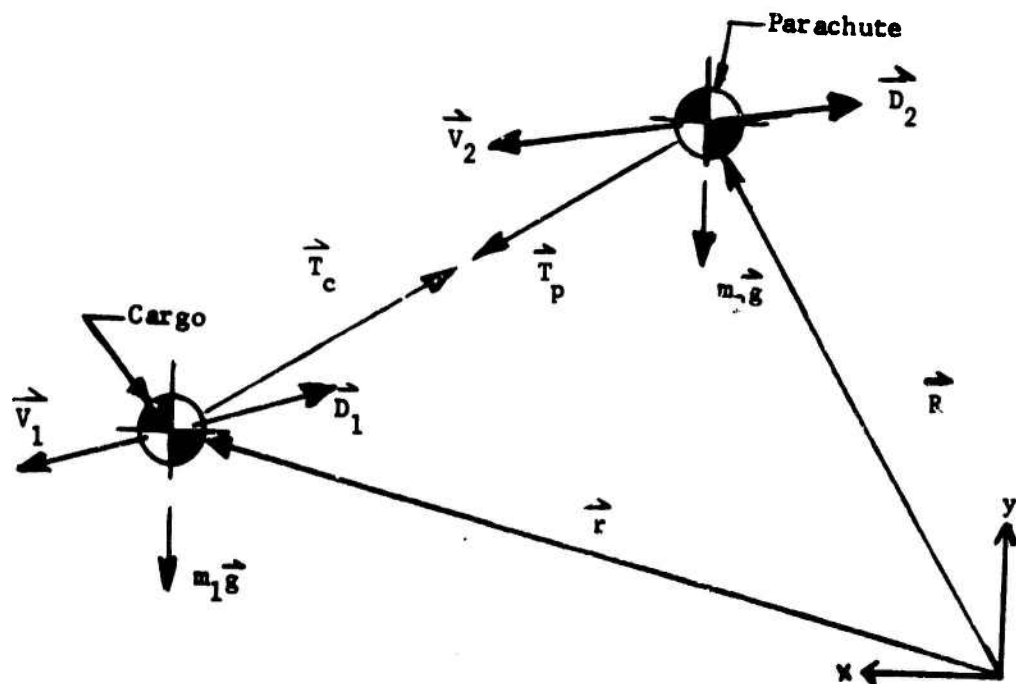
For the purposes of this analysis the air speed vector is defined as follows:

$$\text{Cargo: } \vec{v}_{\text{cargo}} + (-\vec{v}_{\text{wind}}) = \vec{v}_1$$

$$\text{Parachute: } \vec{v}_{\text{chute}} + (-\vec{v}_{\text{wind}}) = \vec{v}_2$$

where \vec{v}_{wind} is the wind velocity vector at a specified altitude.

Although the actual program is three dimensional, the graphic presentation below, which shows the forces acting on the cargo and parachute is shown only in two dimensions for simplicity.



Equation of motion of the cargo:

$$m_1 \ddot{\vec{r}} = \vec{T}_c + \vec{D}_1 + m_1 \vec{g} \quad (1)$$

where: $\vec{D}_1 = -\frac{\rho}{2} (C_D A)_{\text{cargo}} \left| \frac{\dot{\vec{r}}}{r} \right| \frac{\dot{\vec{r}}}{r}$

The equation of motion of the parachute is:

$$m_2 \ddot{\vec{R}} = \vec{T}_p + \vec{D}_2 + m_2 \vec{g} \quad (2)$$

where: $\vec{D}_2 = -\frac{\rho}{2} (C_D A)_{\text{chute}} \left| \frac{\dot{\vec{R}}}{R} \right| \frac{\dot{\vec{R}}}{R}$

Since $\vec{T}_p = -\vec{T}_c$ equation (2) can be substituted into Equation (1) to obtain

$$m_1 \ddot{\vec{r}} = \vec{D}_1 + m_1 \vec{g} + \vec{D}_2 + m_2 \vec{g} - m_2 \ddot{\vec{R}}$$

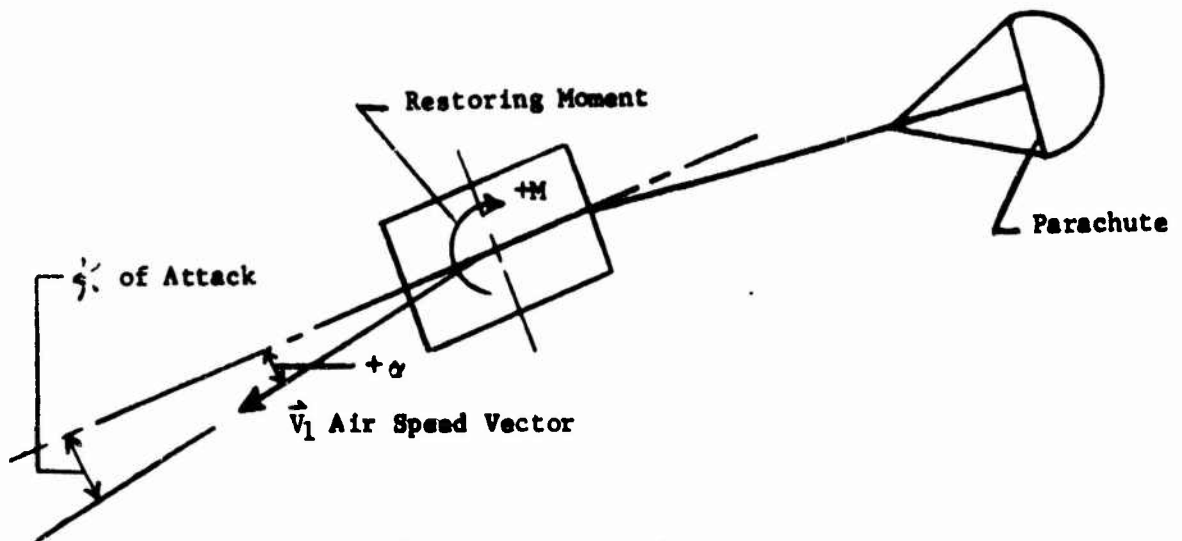
as the basic equation of motion for the cargo.

Program #2

This program assumes the following:

1. The parachute is treated as a point mass.
2. The cargo is treated as a right parallelepiped.
3. The drag force vector on the parachute is always in the opposite direction of the air speed vector.
4. The drag force on the cargo is always normal to the "front face" of the cargo.
5. The lift force on the cargo is always normal to the "bottom face" of the cargo.
6. An aerodynamic restoring moment, specified as a function of angle of attack, tends to rotate the cargo about its pitch axis.

The following sketch should help clarify some of the terms.



The development of the equations of motion for this case proceeded as with Case #1 with the major differences being the change in the treatment of the cargo drag and the addition of the restoring moment. Quite simply, the restoring moment is added to the basic equation of rotation of the cargo such that:

$$\frac{d\vec{H}}{dt} = \vec{l} \times \vec{T}_c + \vec{M}$$

where: $\frac{d\vec{H}}{dt}$ = rate of change of the cargo angular momentum vector

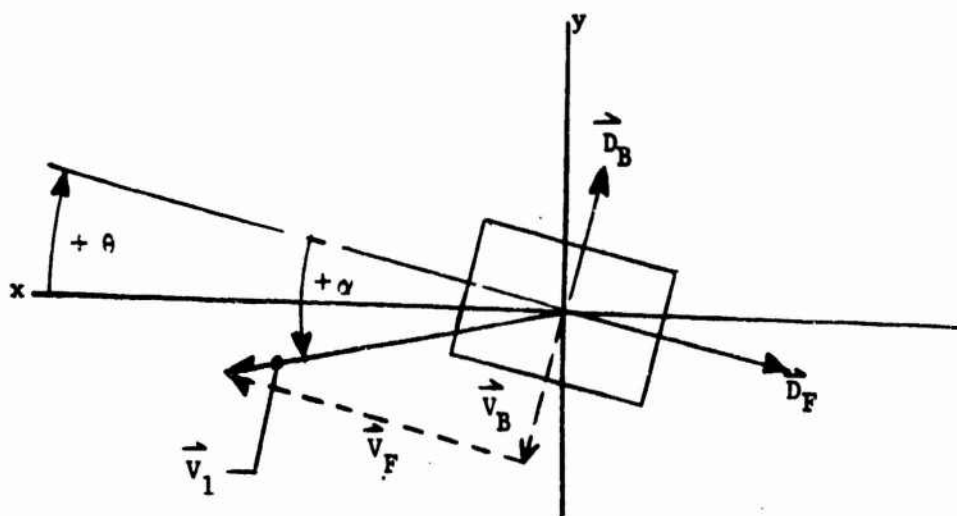
\vec{l} = vector from cargo c.g. to riser attachment point

\vec{T}_c = riser tension vector

\vec{M} = restoring moment vector

If expanded, the equation would result in three moment equations, one about each of the three axes of the cargo. However, since the comparative trajectory analysis was only two dimensional, just one of these equations was used.

The aerodynamic drag is always assumed to act normal to the front face of the cargo and the lift force is always assumed to be normal to the bottom face. These forces are determined by resolving the air speed velocity vector into components normal to the front and bottom faces and computing the forces as indicated on the following page.



$$\vec{v}_F = \vec{v}_1 \cos \alpha$$

$$\vec{D}_F = K_D \vec{v}_1^2 \cos^2 \alpha$$

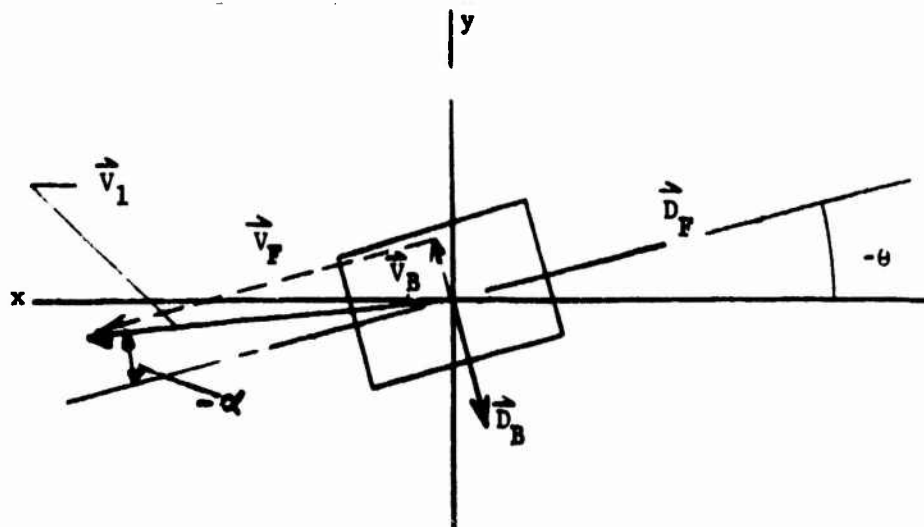
$$\vec{v}_B = \vec{v}_1 \sin \alpha$$

$$\vec{D}_B = K_L \vec{v}_1^2 \sin^2 \alpha$$

$$\vec{D}_x = -(\vec{D}_F \cos \theta + \vec{D}_B \sin \theta) = -\vec{v}_1^2 (K_D \cos^2 \alpha \cos \theta + K_L \sin^2 \alpha \sin \theta)$$

$$\vec{D}_y = -\vec{D}_F \sin \theta + \vec{D}_B \cos \theta = \vec{v}_1^2 (K_L \sin^2 \alpha \cos \theta - K_D \cos^2 \alpha \sin \theta)$$

The above relationships hold for positive values of α , the equations for negative values of α are shown below.



$$\vec{V}_F = \vec{V}_1 \cos \alpha$$

$$\vec{V}_B = \vec{V}_1 \sin \alpha$$

$$\vec{D}_F = K_D \vec{V}_1^2 \cos^2 \alpha$$

$$\vec{D}_B = K_L \vec{V}_1^2 \sin^2 \alpha$$

$$\vec{D}_x = -\vec{D}_F \cos \theta + \vec{D}_B \sin \theta = \vec{V}_1^2 (K_L \sin^2 \alpha \sin \theta - K_D \cos^2 \alpha \cos \theta)$$

$$\vec{D}_y = -\vec{D}_F \sin \theta - \vec{D}_B \cos \theta = -\vec{V}_1^2 (K_D \cos^2 \alpha \sin \theta + K_L \sin^2 \alpha \cos \theta)$$

Again, the modified equations of motion considering lift and drag were extended only to two dimensions for the purpose of comparison to the simplified three-dimensional model. The small difference between the two did not justify extensive program modification for the 3-D model.

Nomenclature

\vec{r}	position vector to cargo C.G.
\vec{R}	position vector to parachute C.G.
\vec{V}_{cargo}	velocity vector, cargo C.G.
\vec{V}_{chute}	velocity vector, parachute C.G.
\vec{V}_{wind}	velocity vector, wind
\vec{V}_1	velocity vector, air speed of cargo C.G.
\vec{V}_2	velocity vector, air speed of parachute C.G.
\vec{D}_1	force vector, cargo drag
\vec{D}_2	force vector, parachute drag
\vec{T}_c	force vector, riser tension on cargo
\vec{T}_p	force vector, riser tension on parachute
\vec{g}	acceleration vector, gravity
\vec{H}	angular momentum vector, cargo
\vec{M}_1	moment vector, aerodynamic restoration of cargo
\vec{l}	position vector, cargo C.G. to riser attachment point
m_1	mass of cargo
m_2	mass of parachute, including the apparent mass of the entrapped air
ρ	air mass density
$(C_D A)_{\text{cargo}}$	product of drag coefficient and reference area, cargo
$(C_D A)_{\text{chute}}$	product of drag coefficient and reference area, parachute
$(C_L A)_{\text{cargo}}$	product of lift coefficient and reference area, cargo
K_D	$\rho/2 (C_D A)_{\text{cargo}}$
K_L	$\rho/2 (C_L A)_{\text{cargo}}$
\vec{v}_F	cargo velocity component normal to the front face of cargo
\vec{v}_B	cargo velocity component normal to the bottom face of cargo
\vec{D}_F	cargo drag force, normal to the front face of cargo
\vec{D}_B	cargo lift force, normal to the bottom face of cargo
α	cargo angle of attack
θ	cargo pitch angle
a dot over a variable	indicates a differentiation with respect to time

B. Concept Description

Preliminary review and background analyses of the high-level container airdrop problem indicated the highest potential for achieving the desired accuracy could be obtained through modification of the present container airdrop system. Consequently, the studies concentrated on the evaluation of different techniques and procedures that are currently used or might be used to implement the present container airdrop system. For example, in the extraction phase, gravity drop and parachute extraction were both evaluated. In the descent phase, a delayed disreef recovery parachute system and a staged stabilization-recovery parachute system were analyzed. In addition, evaluations were made of techniques for determination of the Computed Air Release Point (CARP) and assessing wind effects. Finally, assessments were made of possible problems associated with future use of the Parachute Altitude Recognition System (PARS) currently under development.

1. Standard Container Airdrop System

Concepts evaluated during the study were basically extensions or modifications of the present Container Delivery System (CDS) and wherever possible, standard hardware and procedures were carried over to the high-level airdrop system. The CDS is designed to deliver a number of A-22 containers from aircraft equipped with the dual-rail cargo conveying system. The number of containers is limited by aircraft capacity; typical capacities being 16 containers for the C-130 aircraft and 28 containers for the C-141 aircraft. The A-22 container is a canvas bag and associated straps rigged with paper honeycomb to dissipate landing shock, a simple plywood skid, and either a G-12D, G-13 or T-7 recovery parachute, depending upon the cargo weight. The drop altitude is based largely upon the parachute used, the G-12D requiring 600 feet above ground level (AGL) and the G-13 only 400 feet AGL.

Depending upon the type of aircraft, the containers are placed in single or double rows and secured with standard tiedown equipment. Just before the drop zone is reached, the primary cargo restraint is removed allowing the containers to be restrained by a webbing restraint or gate, and the cargo doors are opened. The pitch angle of the aircraft is increased to approximately 6 degrees as the aircraft approaches the release point, and when the release point is reached a signal is given and the parachute activated cutters remove the gate allowing the containers to roll out. In the C-130 aircraft it takes 5 to 6 seconds for the full load to exit the aircraft.

As the containers leave the aircraft, the recovery parachute for each is deployed by a static line and allowed to inflate to its full diameter. The spacing of the containers as they roll out of aircraft and the sequential deployment of the parachutes are generally effective in preventing interference or entanglement of cargos and parachutes.

The system is simple and reliable in operation. The only major problems appear to be slow functioning parachutes and the proper selection and acquisition of the release point. The parachute problem arises from the low level of drop and the large number of parachutes deployed in a small airspace. Some parachutes will be in the aerodynamic shadow of other parachutes and do not get enough air to function. If there is enough vertical airspace, the cargo and parachute will merely fall past the other parachutes into clear air and then function properly. In high-level airdrops there will be adequate airspace so this trouble should be diminished. The problem with selection and acquisition of the release point is basic to all airdrop systems, and therefore, not a disadvantage peculiar to CDS systems.

2. Stabilization Methods

The methods used to stabilize the high velocity descent portion of the airdrop may be separated into two general categories: recovery parachute systems and staged deceleration systems.

a. Recovery Parachute Systems

Recovery parachutes are usually modified by "reefing", using a line or lines to prevent full opening of the parachute. This may be accomplished in a number of ways, a usual method being to pass the line through rings on the skirt edge and pull the skirt of the parachute closed; another is to attach a line to the center vent and pull it down below the skirt edge. The system descends with the parachute in this reefed condition and at an altitude above the drop zone sufficient to permit inflation and deceleration to a safe landing velocity, the reefing is released by a reefing cutter and the parachute inflates to full diameter. Actuation of the reefing cutter can be controlled by a fixed time delay or a height sensor. The use of a height sensor will improve the accuracy of the system considerably.

These methods have the advantage of using only one parachute for the entire descent which saves the packing and rigging time for a second canopy, but this saving is partly offset by the additional time needed to reef the main recovery parachute. The principal disadvantage of the system is, that even when reefed to the smallest stable diameter, a recovery parachute still has considerable aerodynamic drag, which increases the time of fall giving more time for wind effects to affect system accuracy. Also there is a tendency toward malfunction of disreefing systems due to twisting and whipping of the suspension and reefing lines.

b. Staged Deceleration Systems

Staged stabilization systems employ a small parachute sized to stabilize the cargo container during the descent phase. At a height above the drop zone sufficient to deploy the recovery parachute, and decelerate the cargo to a safe landing velocity, a device is actuated to accomplish the staging action. Staging can be accomplished from a fixed time delay, but a height sensing device improves system accuracy and is much preferred. This method allows the highest rate of fall and shortest time in the air, thereby decreasing the effects of winds.

A preliminary investigation was performed to determine the minimum size parachute required to achieve stability of the cargo container. This was found to be 4 feet diameter for ring slot canopy (see Section IV-A-2-b) which has a drag coefficient - area product ($C_D A$) of approximately 12 square feet. By comparison, Riffle (8) shows that a G-12D recovery parachute reefed to zero mouth diameter still has a $C_D A$ of approximately 200 square feet.

According to Heinrich (5) in his work on stabilization of the A-22 container, the minimum size parachute to keep an initially non-rotating A-22 container from rotating is a 5.33 foot solid flat circular, ring slot, or ribbon canopy, or a 4 foot ribless guide surface parachute. In addition, the results showed that the static stabilization requirements were independent of cargo density so that one size stabilization parachute could be used for all cargos.

The ribless guide surface parachute was used in early computer simulations because it achieved stability with the least drag. However, late in the study it was found that the G-12D canopy would not open reliably at the descent velocity allowed by the 4 foot ribless guide surface parachute so the stabilization parachute had to be increased in size to give lower descent velocities. The descent velocity above which the G-12D will not open reliably is reported to be 225 fps.¹ To achieve this value on a 2200 lb. container, the size of a flat circular parachute must be about 7 feet. This then establishes the sizing of the stabilization parachute on a 2200 lb. container rather than stabilization considerations.

An alternate for the G-12D parachute is the 64 ft. annular ring parachute. The opening characteristics of this parachute were not available for this study, but if it is determined that this equipment can be deployed at higher velocities the small stabilization parachutes may be employed. Also, as shown elsewhere in this report, A-22 container loads weighing 1900 lbs. or less have a descent rate using a 4 ft. ribless guide surface that is less than the critical value for the G-12D so the class of loads requiring the larger stabilization parachute is fairly small.

-
1. Recent experiments using a vent pull down technique indicate that this opening problem with the G12-D parachute may have been solved. Successful deployments at velocities up to 250 fps have been reported. If this technique proves to be reliable, the 4 ft. ribless guide surface parachute can be used to stabilize all weight conditions of the A-22 including the 2200 pound configuration.

3. Extraction Systems

a. Gravity Extraction

Both of the extraction systems studied make use of aircraft equipped with a roller-conveyor system, and in both systems the containers comprising the total airdrop load are placed on the rollers in a compact group, two abreast. From this point the two systems differ. For the gravity extraction system the cargos are restrained during flight by securing the containers to the aircraft in a suitable manner. Static lines are attached to the overhead cable in the aircraft for deployment of the parachutes. Upon nearing the Computed Air Release Point (CARP) the aircraft is placed in a nose-up attitude (6°) and cargo restraint, other than that provided by the release gate, is removed. At the drop signal, the gate is cut and the cargos are allowed to roll out with no interconnection between cargos, and the stabilization parachutes are deployed by the static lines. This results in emptying the aircraft in about six (6) seconds, and the individual containers deploy in a configuration similar to the pattern described in Figure 12.

b. Group Extraction

Studies made show that, in group extraction, the total load of containers must exit in one or, at most, two distinct groups in order to achieve quicker exit than that by gravity extraction. This means that the cargos of the airdrop must be interconnected and, because extraction accelerations on each cargo are not to exceed 1.5g and the total extraction force must be designed to be 1 to 1.5 g's on the entire load, each member of the total load must be individually attached directly to the extraction harness. This idea is illustrated in Figure 14. The harness or bridle would be threaded down both sides of each row of the stowed containers with each container attached to it. The mechanism to disconnect the cargos from the harness after extraction must be set and armed.

Since the extraction force is to be applied to all of the containers from one end and must act in the horizontal direction (for which they were not designed) some changes must be made to the method of preparing and rigging the containers. These changes would be in a manner similar to that of preparing cargos for Low-Altitude Parachute-Extraction System (LAPES)(9). Heavy end boards would have to be positioned and attached to the forward side of the containers so that the extraction load would be spread evenly. Extraction straps would have to be attached in a manner that would allow the individual containers to separate clearly from each other after exit from the aircraft.

Extraction of A-22 containers by parachute has been studied experimentally by Miller (10) in a project that indicated limited feasibility using reefed and unreefed 15 ft. ring-slot extraction parachutes. For these tests the maximum number of containers extracted simultaneously was six (two

rows of three) with a peak accelerating force of .5g on each of the last two containers. The force from the extraction parachute was transmitted to the containers through a bridle which was cut after the containers had moved approximately 40 inches; well before they had left the aircraft. Using this technique and equipment, the extraction time for three pairs of containers would be longer than that for CDS gravity extraction of 16 containers from a C-130 aircraft. From foregoing results it appears that gravity extraction would be preferred when evaluated from the standpoint of performance, equipment, and manpower.

4. Release Point Selection and Acquisition

A major source of error in airdrop operations is in the selection and acquisition of the point in space to release the cargos such that they land in close proximity to the target in the drop zone. The point in space is generally called the Computed Air Release Point (CARP) or, in some methods, the High Altitude Release Point (HARP). The first step in selection of the CARP is to find the trajectory that the cargos will take when dropped. The trajectory of an airdropped unit without the effects of winds can be found experimentally as a function of aircraft forward velocity as shown in tests by Claunch(6). For a particular airdrop the no-wind trajectory must be modified by the effects of winds plus aircraft heading and true course, and as mentioned in other parts of this report, wind data must be current at the time of the airdrop to be of use. Working the reverse of the trajectory back to the aircraft from the target will determine the CARP and then navigational directions must be transmitted to the pilot in order to reach it. In general, this would entail a change of course and heading which in turn means a recalculation of the CARP, and so on. A corollary to the computation is knowing when the aircraft has actually reached the CARP. Conventional airdrop procedure has not been able to approach the ideal procedure above. In the conventional system, the release point is computed on an expected course and heading to be used in the vicinity of the target. To reach the CARP, a prominent ground feature known as an offset aiming point (OAP) is selected and its relation to the expected course is plotted. The closest point on the flight path to the OAP is calculated, the time of flight to the CARP is computed and the aircraft is put on the assumed flight path toward the CARP. When a designated crew member decides that the aircraft is opposite the OAP (usually by sighting past a door or window), he signals the co-pilot, who starts a stopwatch. The aircraft is brought to the six-degree, nose-up attitude and, after the calculated time has elapsed, the signal to drop is given.

There are a number of opportunities for error in this method. First, the wind data used may not be current by the time the aircraft reaches the CARP and may have actually been measured at another location. Secondly, the aircraft true course, heading and flight path may be different because of changing winds. Furthermore, there are the human errors in sighting on a ground feature, and in maintaining course and heading for an aircraft in a nose-up attitude. Finally, the nose-up attitude reduces downward visibility and the pilot's reference to ground features.

Recently, improvements to the above methods have been studied, particularly methods that make use of the Ground Radar Aerial Delivery System (GRADS), in which the aircraft is guided to the CARP by the methods and equipment of Ground Controlled Approach (GCA) landing systems. (6,11) The studies report that GRADS is not particularly effective and recommend that the system be used only as an interim technique. Replotting of data from (11) indicates that if the aircraft had indeed released their cargos from the GRADS supplied

CARP, the cargos would have landed within 200 yards of the target; however, the aircraft missed the CARPs consistently, often by thousands of yards.

Munson⁽¹²⁾ gives the results of a study to find aircraft flap settings which would ease control of the aircraft in the nose-up attitude, and the use of a ballistically released cargo restraint gate which would make the release of cargo more predictable.

Ferrier⁽¹³⁾ shows that correct positioning of the aircraft at the CARP can be improved by the use of a visual sighting system, but gives no way to improve the calculation of that CARP. Two other reports by Ferrier^(14,15) discuss the findings of studies of the Adverse Weather Aerial Delivery System (AWADS) which is an integrated combination of aircraft navigational radar and a navigational computer. This system has the ability to sense both aircraft heading and course plus the direction and magnitude of the winds affecting the aircraft so that it can automatically compute and update the location of a release point. This system demonstrates good potential and the problems reported seem to concern specific equipment and not the system itself. The AWADS technique approaches the problems surrounding CARP acquisition in the manner in which it must be approached in order to achieve success.

5. Parachute Altitude Recognition System

A device currently under development which can be used to deploy the recovery parachute for the high level airdrop system is the Parachute Altitude Recognition System (PARS) which is a radar sensor capable of measuring the altitude above ground level of the cargo container. The design and development of this sensor was not a part of this study but because of the interaction of the systems, some knowledge of the placement, method of operation, and physical characteristics of the system was required.

Physical details of the PARS equipment were not available for this study, but specifications for the equipment require that it can be mounted on the cargo container so that it will have an unobstructed view of the ground when the stabilized cargo is descending in a vertical path. It will be lightweight and have sufficient power output to actuate a parachute deployment device.

The sensor is to be designed so as not to be activated by other members of a single plane load of containers although the problem of erroneous activation by cargos from other aircraft during a multiple airdrop operation did seem possible. In addition it was felt that under certain circumstances, a cargo aircraft could be sensed as "ground" and therefore a study was made to evaluate possible system interference. The field of view of the sensor is conical with an included angle of 80 degrees, the axis of the cone being directed normal to the base of the cargo container. Using a staged parachute system, the cargos have to fall approximately 500 feet or about 6 seconds before the field of view does not include anything above a horizontal plane passed through the cargo. In other words, the PARS sensor should not activate until the stabilized container has fallen for 6 seconds, allowing enough travel along the trajectory to avoid including the aircraft in the field of view. Since the cargos are expected to be dropped from high levels, the activation delay is not expected to be a problem in the staged system performance.

One factor that may affect the system is the accuracy of the sensor. The advantages of the staged parachute airdrop system is predicated upon minimum altitude initiation of the recovery parachute when the cargo is traveling with a nearly vertical velocity of 240 fps. Studies indicate that the PARS equipment must be capable of deploying the recovery parachute within ± 50 feet of the theoretical deployment point, otherwise system accuracy will be unduly compromised. This situation was quantitatively evaluated and is discussed on pages 97 and 98 of this report.

C. Results of Analysis

The various extraction, stabilization and recovery configurations that were established during the background investigations were examined for various combinations of wind conditions selected from the eighteen (18) cases described in Section IV-A-2-a. Trajectories for cargo-parachute combinations were analyzed with the Three-Dimensional Airdrop Program utilizing the CDC 6600 computer. Throughout the project it was assumed that sufficient navigational equipment would be available to insure that the aircraft could achieve the computed Air Release Point. In addition, for purposes of the computer analysis, it was assumed that the PARS electronic altitude sensor would be sensitive enough to initiate deployment or disreef of the recovery parachute at the preset altitude with complete reliability.

1. Extractions Systems

Gravity and parachute extraction configurations were analyzed in the three-dimensional airdrop program for no-wind conditions. Both configurations utilized a high velocity descent phase and a low altitude, low velocity recovery phase. In the gravity extraction system, the stabilization parachutes were assumed to be sequentially deployed by static lines attached to the aircraft while, for the parachute extraction method, deployment of the stabilization parachutes began as the last cargo cleared the ramp edge.

a. Gravity Extraction

The relative position of the cargos at the end of the extraction phase is shown in Figure 12 for a full complement of containers from a C-130 airplane. The computer simulation run for a no-wind condition indicates that the total spread at drop zone will be 753 feet. This is illustrated in Figure 15. Similar analyses for the C-141 aircraft indicate that the total spread at the ground will be 1177 feet.

b. Parachute Extraction

The relative position of the containers parachute extracted from the C-130 and C-141 aircraft with the stabilization parachutes sequentially deployed as described in Section IV-B-3-b is illustrated in Figure 13. Computer simulations run for this group of containers shows the total spread at the drop zone to be 885 feet which is significantly larger than for the gravity extraction method. This spread is illustrated in Figure 16. Similar analyses for the C-141 airplane were not run since the experience with the C-130 indicated the gravity extraction system was much the better of the two systems. The problem with the parachute extraction system rests with the deployment of the stabilization parachutes because it would appear that if the stabilization parachutes could be deployed without danger of

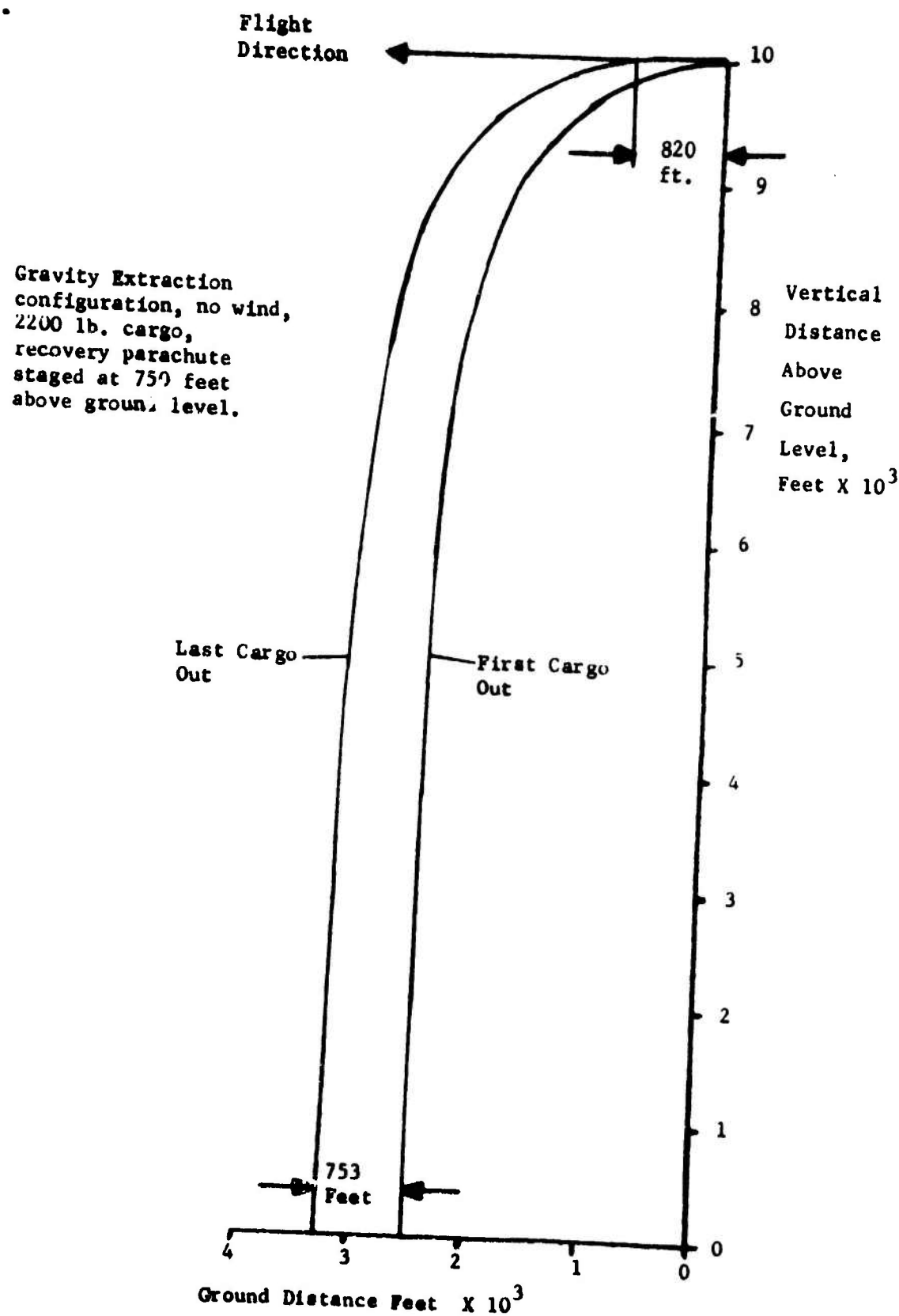


FIGURE 15 - CARGO SPREAD AT DROP ZONE-GROUND EXTRACTION

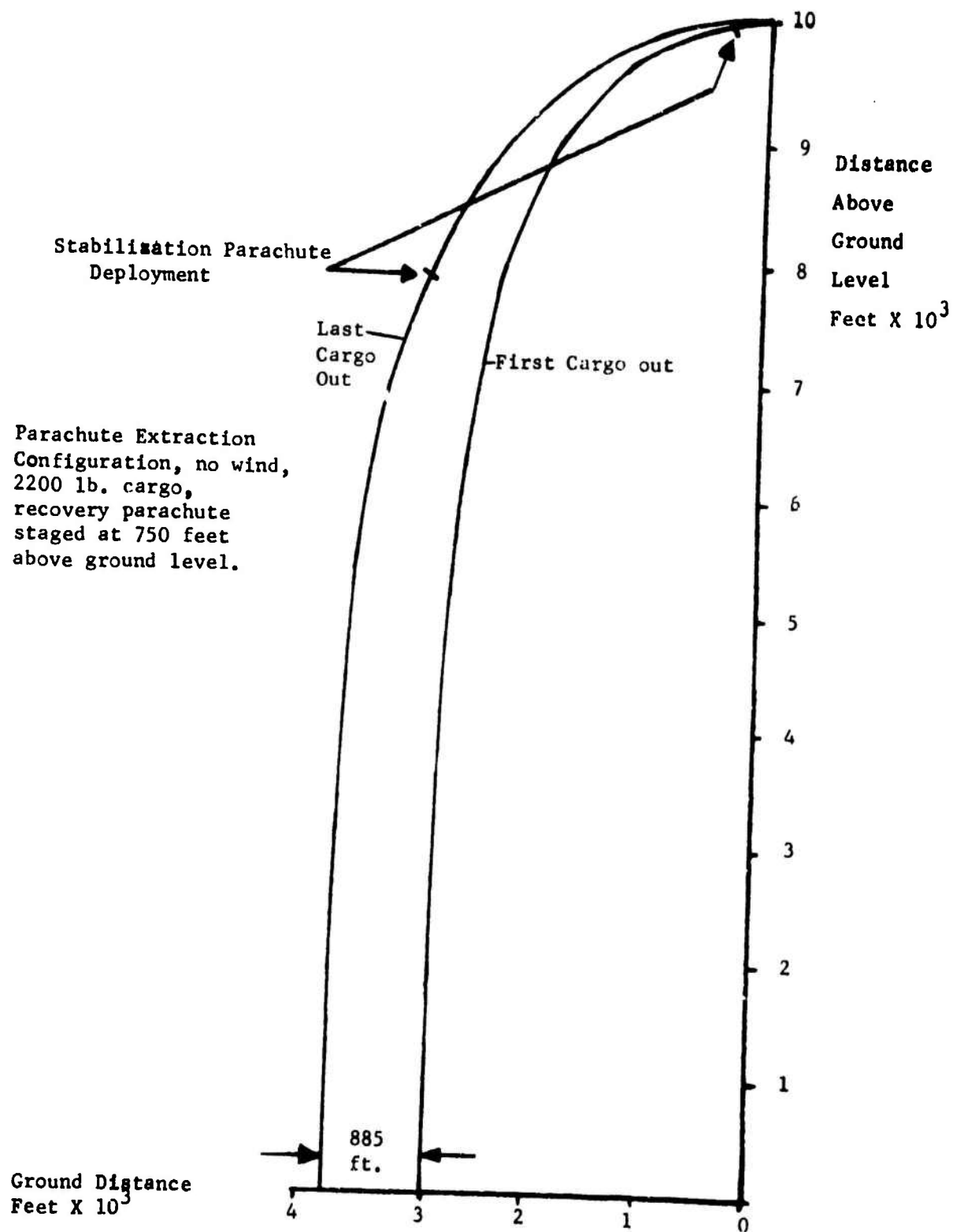


FIGURE 16 - CARGO SPREAD AT DROP ZONE - PARACHUTE EXTRACTION

entanglement while the containers were still compactly grouped, the spread at the drop zone would be quite small. Other deployment methods were analyzed without improvement, but analyses of this type depend upon the generation of concepts and the study could not be exhaustive in this respect. Until a suitable concept for deploying the stabilization parachutes is conceived, the gravity extraction method must be considered the better of the two methods.

2. Wind Effects Study

The initial computer simulations of winds effects were to assess limit conditions and therefore utilized the highest wind at drop altitude, largest resultant wind, largest angular change with altitude, and largest surface wind from the wind cases (discussed in Section IV-A-2-a) that had data points for altitudes at 150 - 175 m AGL. The method of assessment of the simulations was to plot the positions of the cargos in the X-Y (horizontal) plane at one-second intervals. In order to measure miss distances an aim point had to be synthesized by reversing the release point calculation as put forth by Chaunch(6) and Ferrier (14)(15). There a reverse azimuth of the wind is plotted from the aim point after which a distance determined by the time of fall times the wind velocity and reduced by a proportional factor, is laid out on the azimuth. The proportional factor accounts for the fact that the parachute-cargo combination does not drift completely with the moving air mass. From the point plotted above, the reverse azimuth of the aircraft true course is laid out and a distance determined by an empirical rate of fall multiplied by the time of fall is plotted. This point is the Computed Air Release Point (CARP).

The simulation plots were done in a reverse manner as follows. Placing the release point at the origin of the coordinate system, the aircraft true course was plotted, and on it was placed the no-wind landing point determined from the no-wind simulations made in the extraction study of the proceeding section. From the no-wind landing point, the direction of the wind vector was laid out and a magnitude representing cargo drift due to the wind was calculated by multiplying the wind velocity by the time of fall and located along this vector. Three different wind vectors were used in the study, namely; the resultant wind vector, the wind at drop altitude, and the resultant of the wind at altitude and the ground. Plots of the initial simulations are shown in Figure 17, 18, 19, 20, and 21. From these plots an average proportional factor was calculated by measuring the distance from the no-wind landing point to the point on the wind vector that was closest to the actual landing point, and dividing that distance by the calculated wind drift. These decimal fractions were averaged for the five initial cases and the average was .328 of the resultant wind drift.

The affect of the initial cargo velocity on the no-wind landing distance was studied for the 7 ft. solid circular stabilization parachute by running several simulations at various initial cargo velocities. It was found that the relationship was nearly linear so this relationship was used in making subsequent plots.

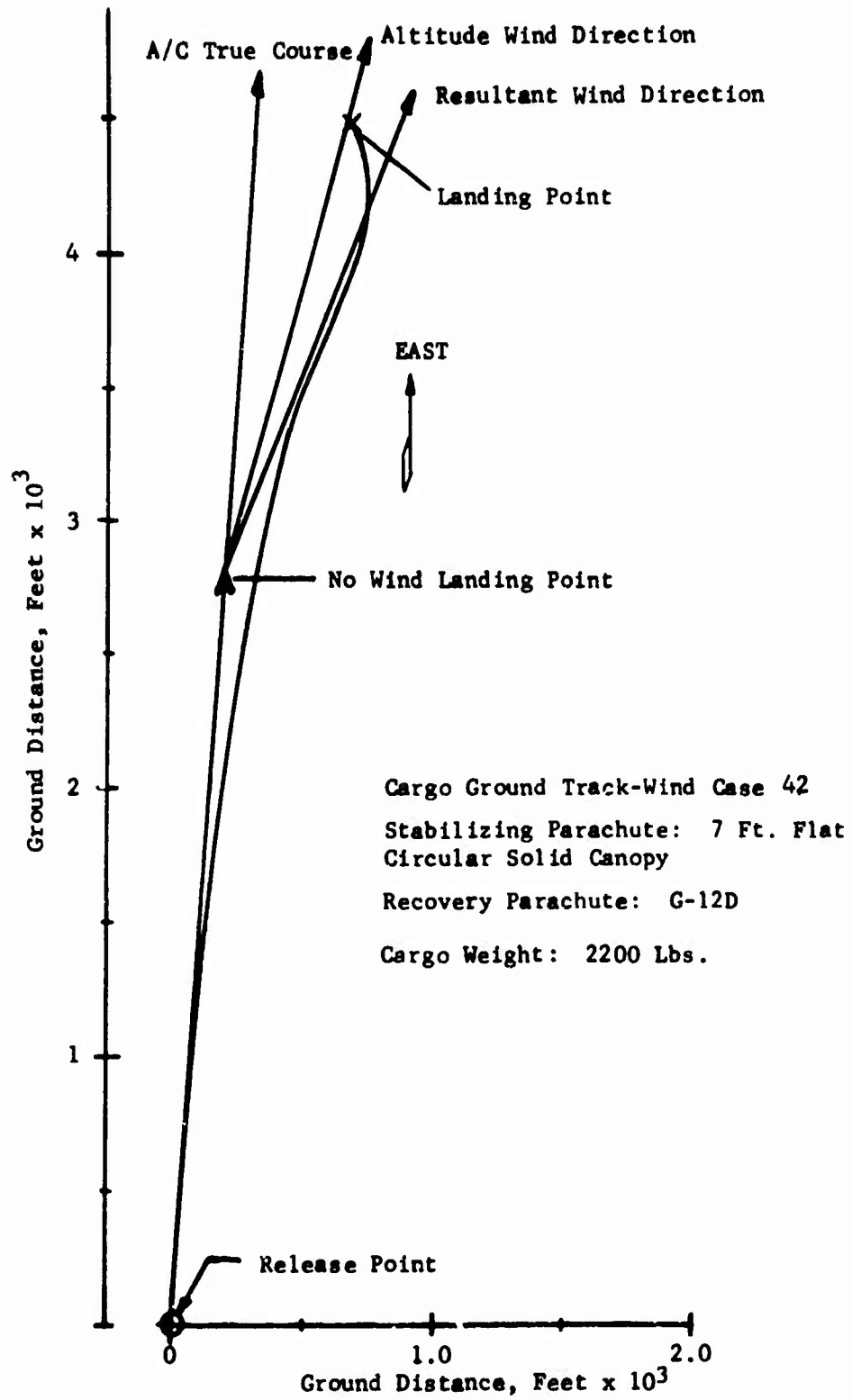


Figure 17

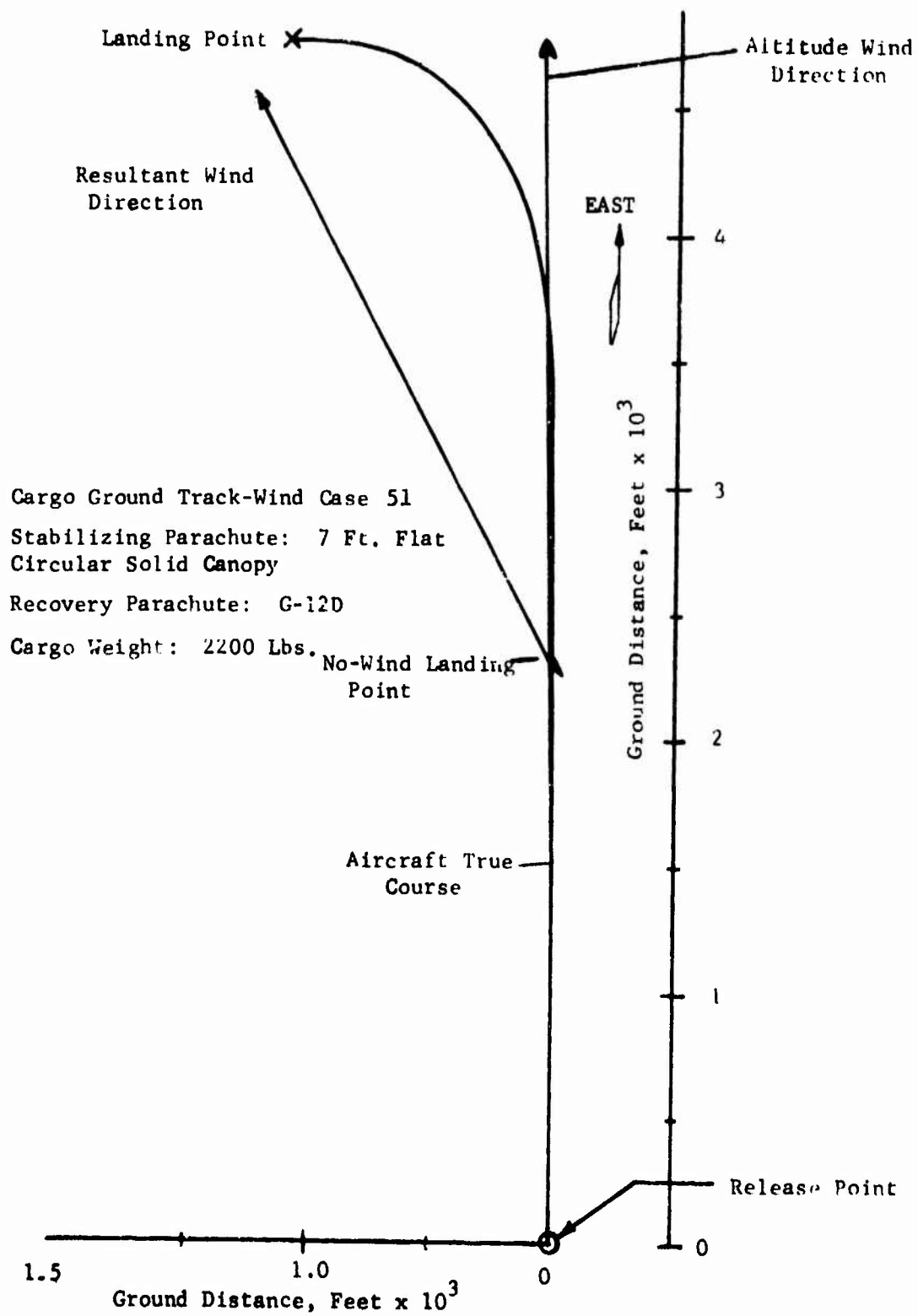


Figure 18

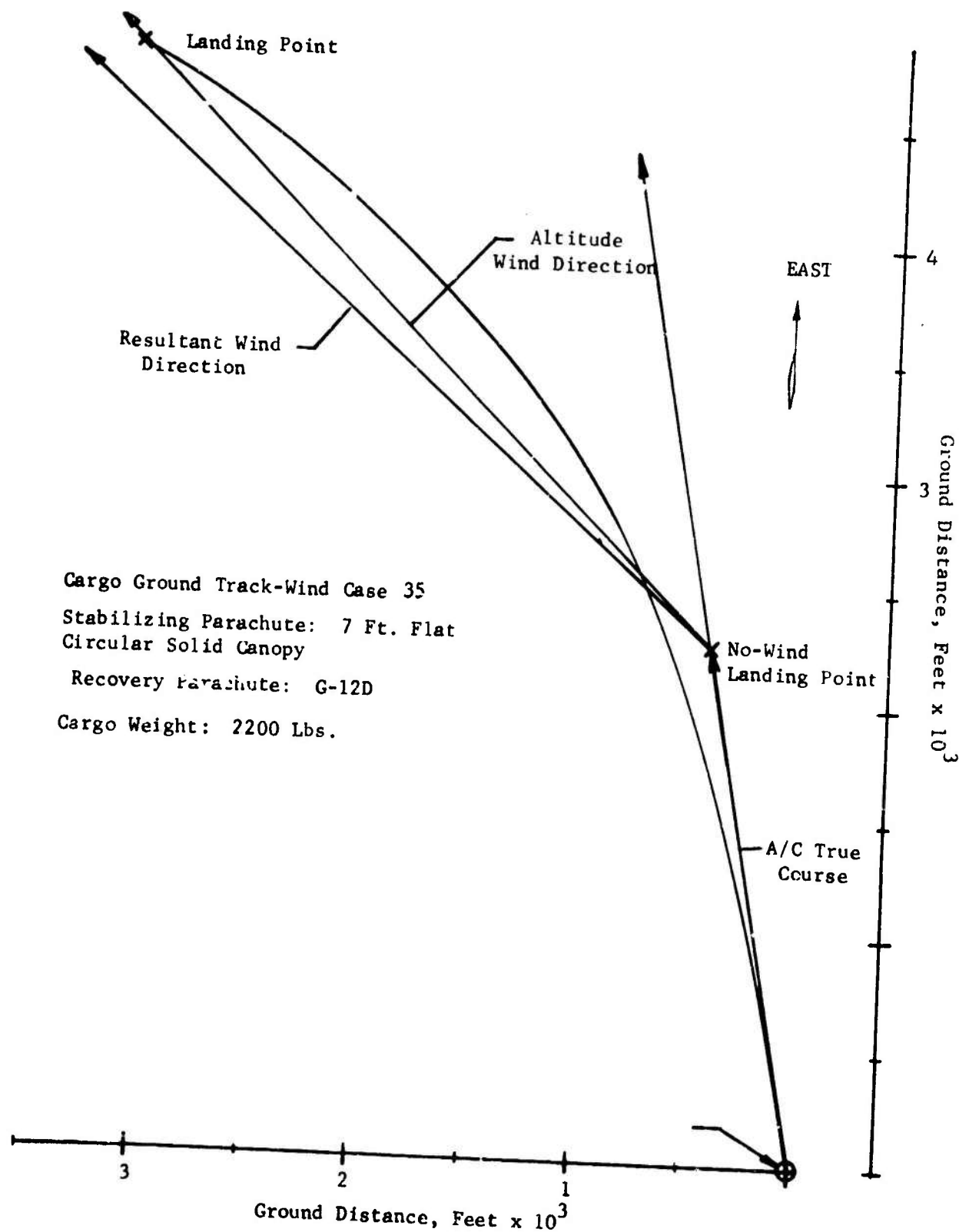


Figure 19

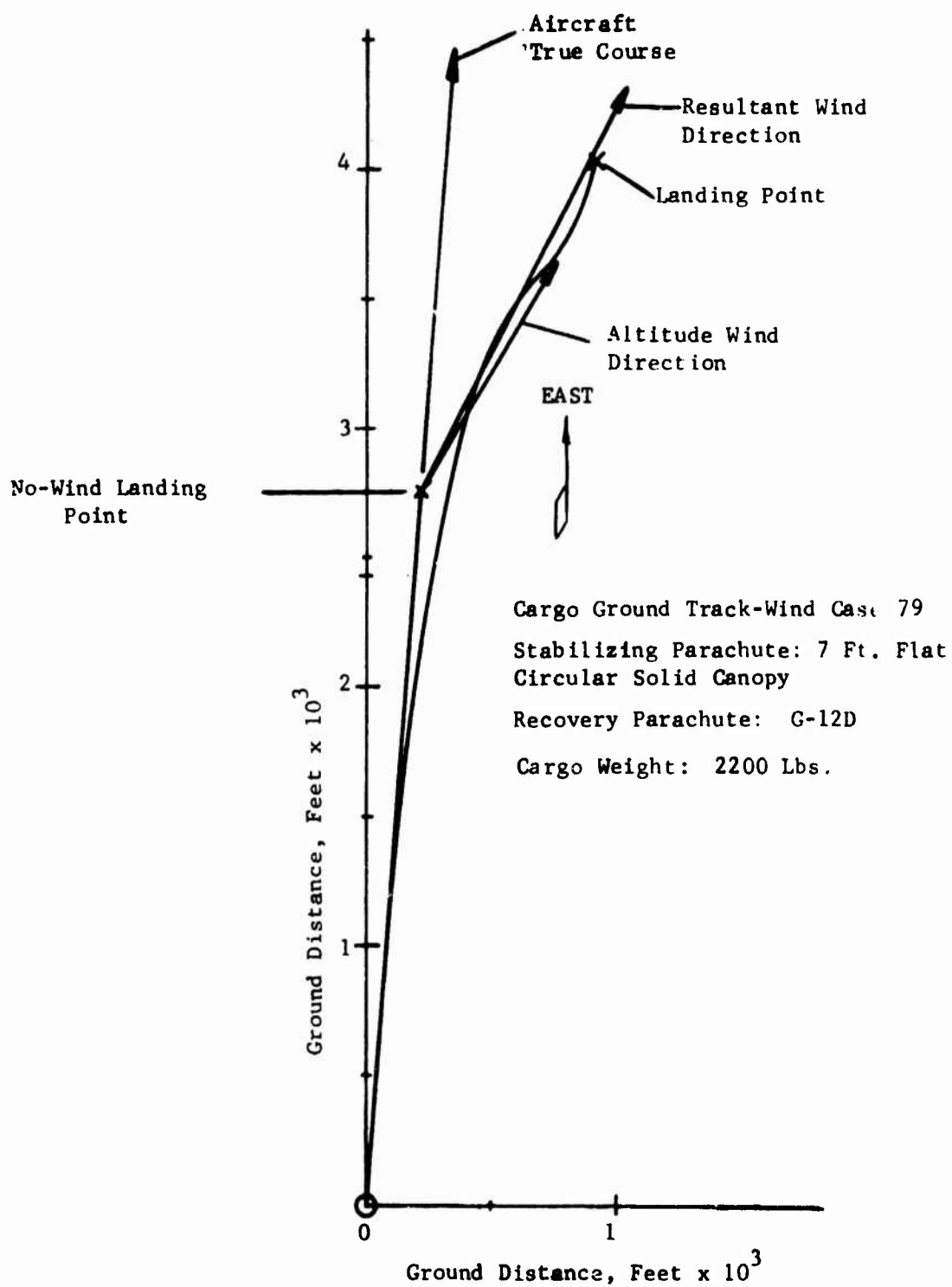


Figure 21

The initial series of simulations, using the resultant wind, showed good possibilities for predicting the landing point of a cargo released from high level and indicated that a suitable release point could be found. The resultant wind used in these simulations is very difficult to assess in reality and so the suitability of using more practical wind information warranted study. At this point in the program, it was also decided to use only wind cases with velocities of 15 knots or less at the surface. The wind condition at the release altitude is the easiest to obtain and there is a good possibility that the ground wind conditions at the drop zone may also be available. Simulations were computed using these types of information for various airdrop configurations.

The first group of these simulations was made with a seven-foot solid flat circular stabilization parachute and the cargo ground tracks for these are shown in Figures 22, 23, 24, 25, and 26. The proportional wind factor for these cases was found to be .844 of ground-altitude wind drift and .468 of altitude wind drift. Using these factors, circular errors for the 7-foot parachute system were found and are shown in Figure 27 and 28. The system results in good accuracy with half of the drops landing within 175 meters of the aim point using the altitude wind and within 125 meters using the ground-altitude wind.

Another series of simulations were performed using a four foot ribless guide surface stabilization parachute and the cargo ground tracks for these are shown in Figures 29, 30, 31, 32, 33, and 34. The proportional factors for the altitude and ground-altitude wind were .516 and .889 of total wind drift, respectively. The circular error plots for the two factors are shown as Figure 35 and 36. These confirmed the expectation that higher rate of fall improved accuracy for half of the cargos landed within 110 meters of the aim point based on the altitude wind and within 75 meters of the aim point for ground-altitude wind inputs, a clear improvement over the larger stabilization parachute.

As a further comparison, simulations were made using a reefed G-12D parachute as a stabilization system. The circular error plot for this configuration using ground-altitude winds is presented in Figure 37 and shows clearly the effect of the winds on the slow falling cargo. These simulations also gave an opportunity to check the simulated predictions against published data, such as those presented by Claunch (6). The computer simulations gave good agreement with the measured rate of fall of a cargo container stabilized with a reefed G-12D parachute. No simulations were made using a reefed 64 ft. annular ring parachute, but it is reasonable to conclude that the results would be similar to the G-12D, since this parachute has similar drag characteristics.

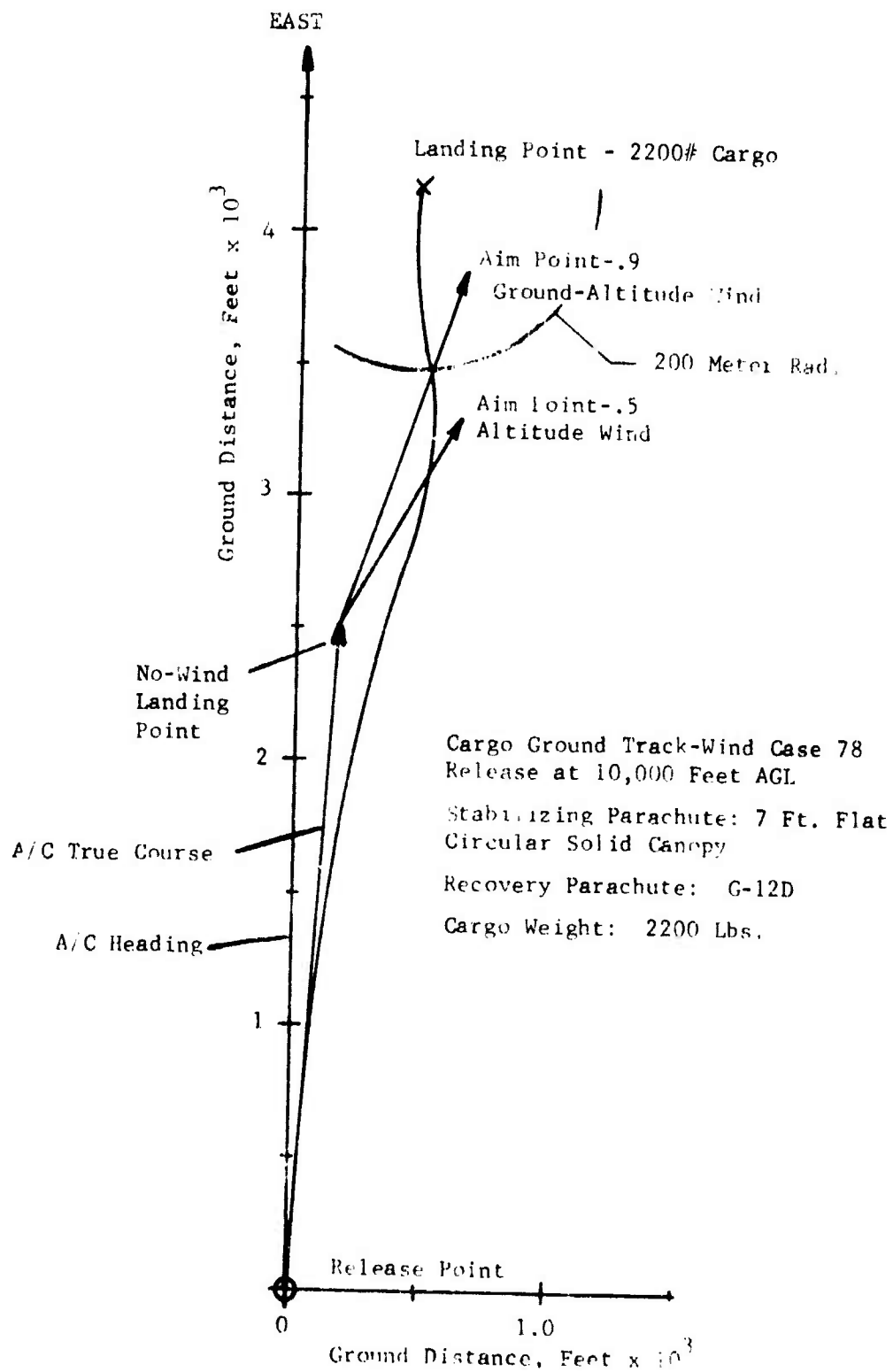


Figure 22

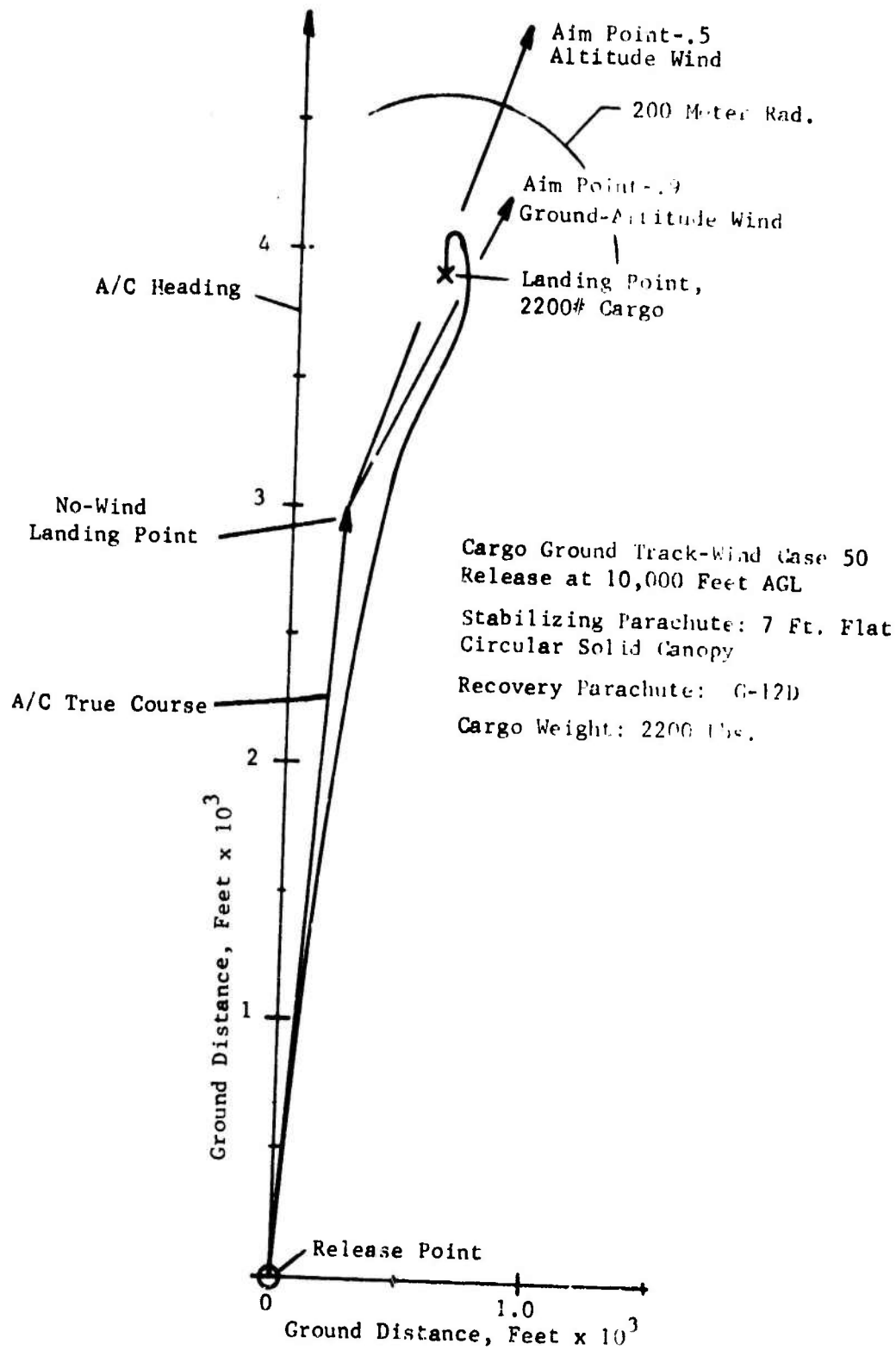


Figure 23

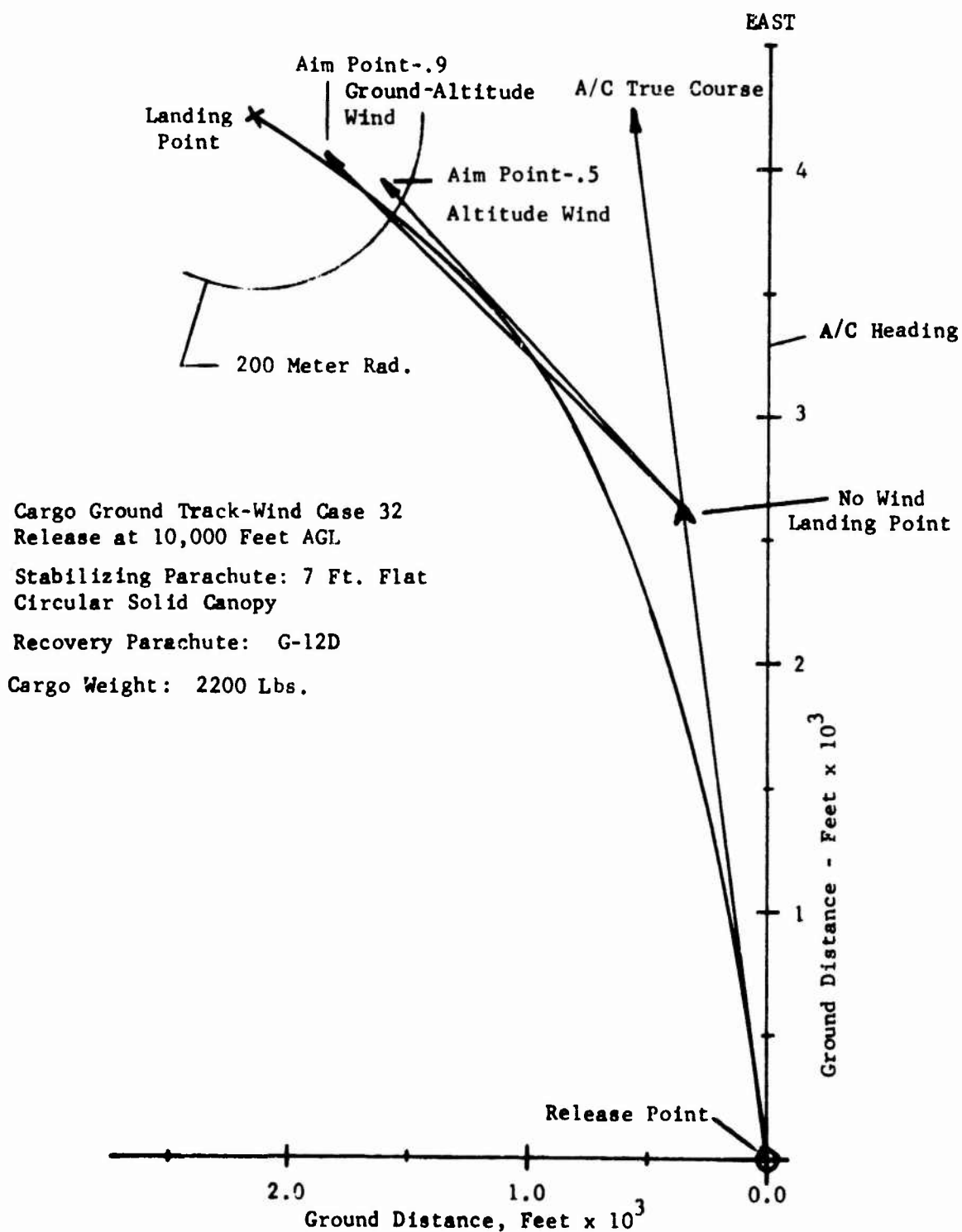


Figure 24

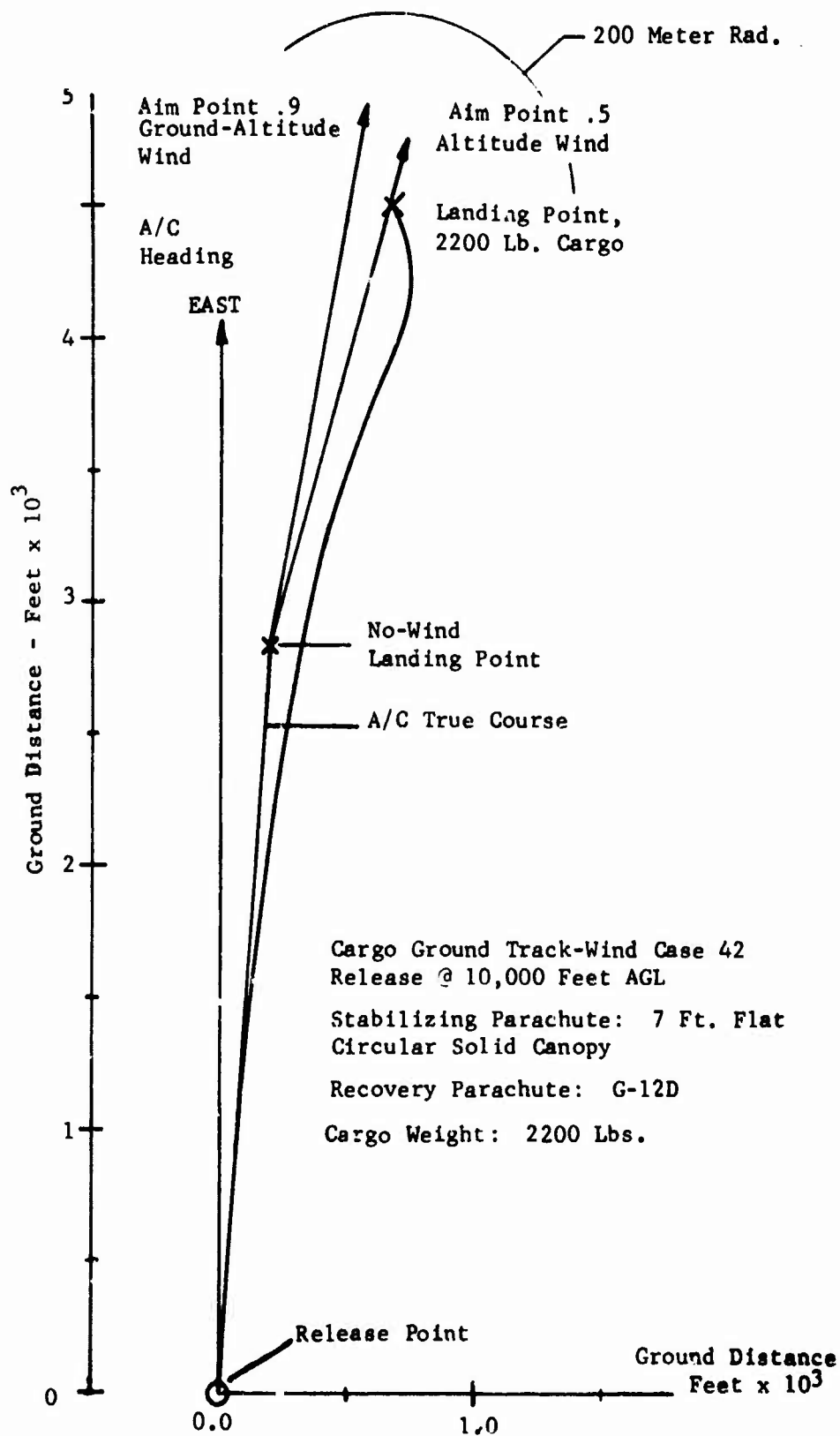


Figure 25

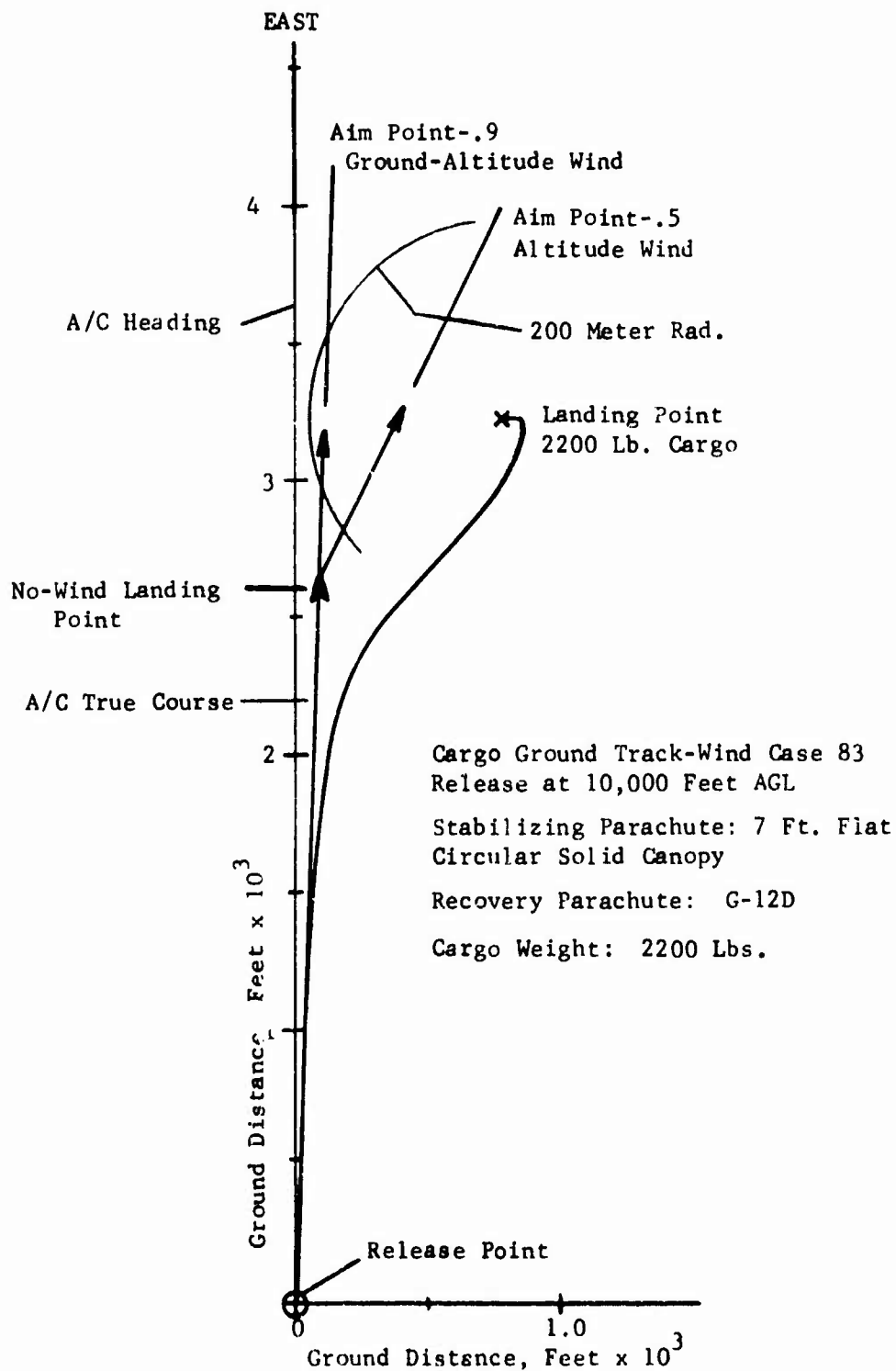
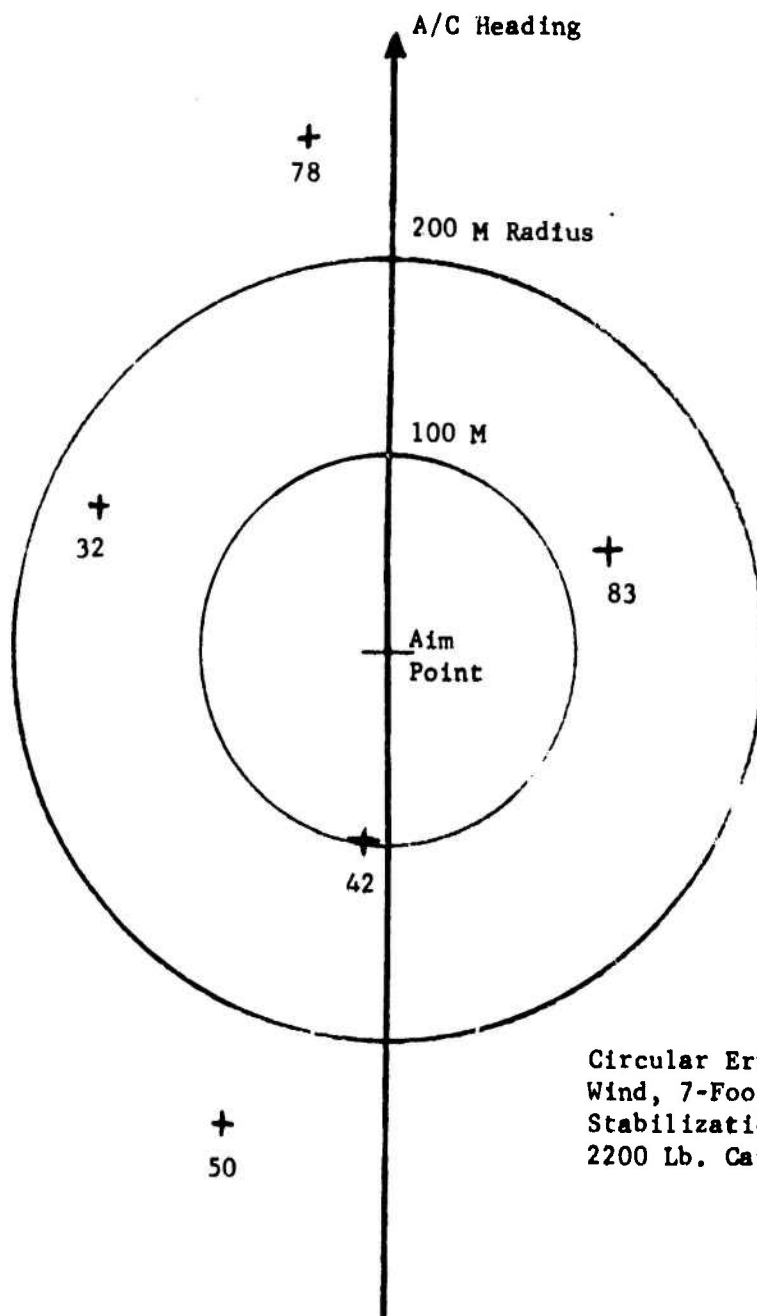
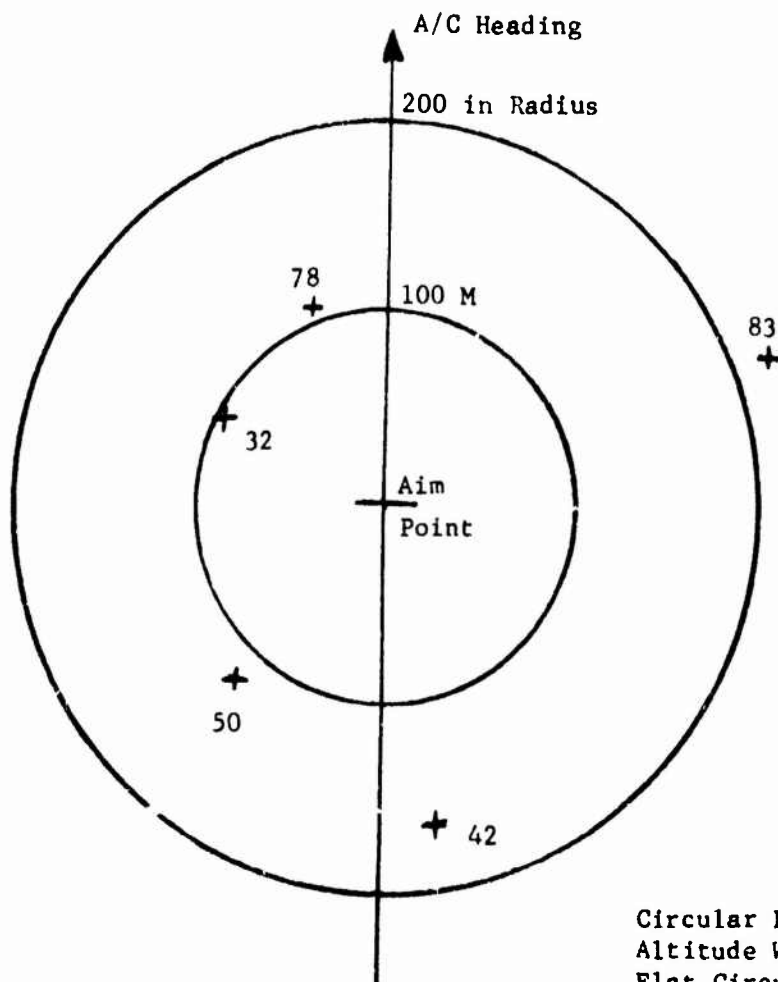


Figure 26



Circular Error Using Altitude
Wind, 7-Foot Solid Flat Circular
Stabilization Parachute
2200 Lb. Cargo

Figure 27



Circular Error Using Ground-
Altitude Wind, 7 Foot Solid
Flat Circular Stabilization
Parachute 2200 Lb. Cargo

Figure 28

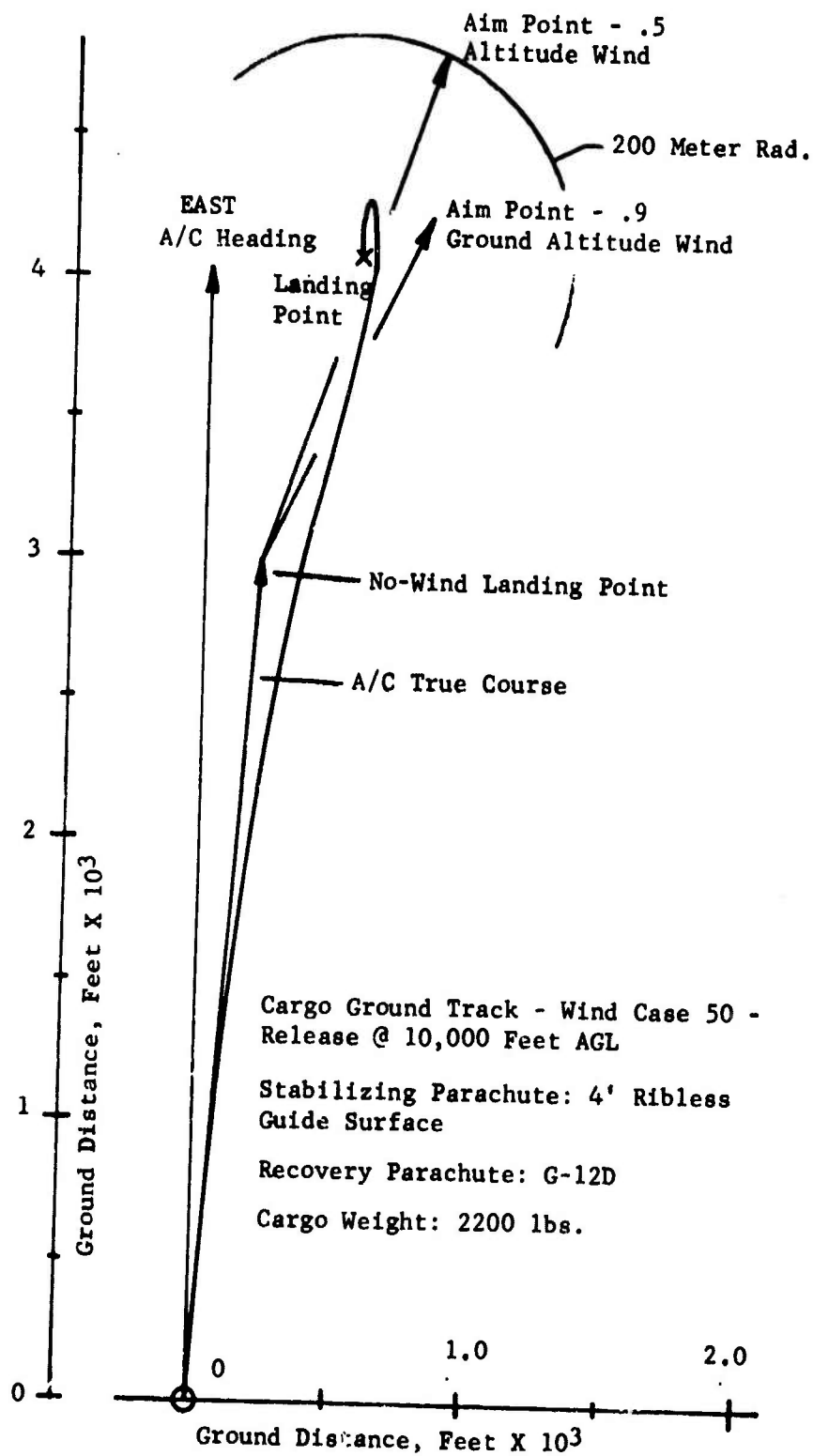


Figure 29

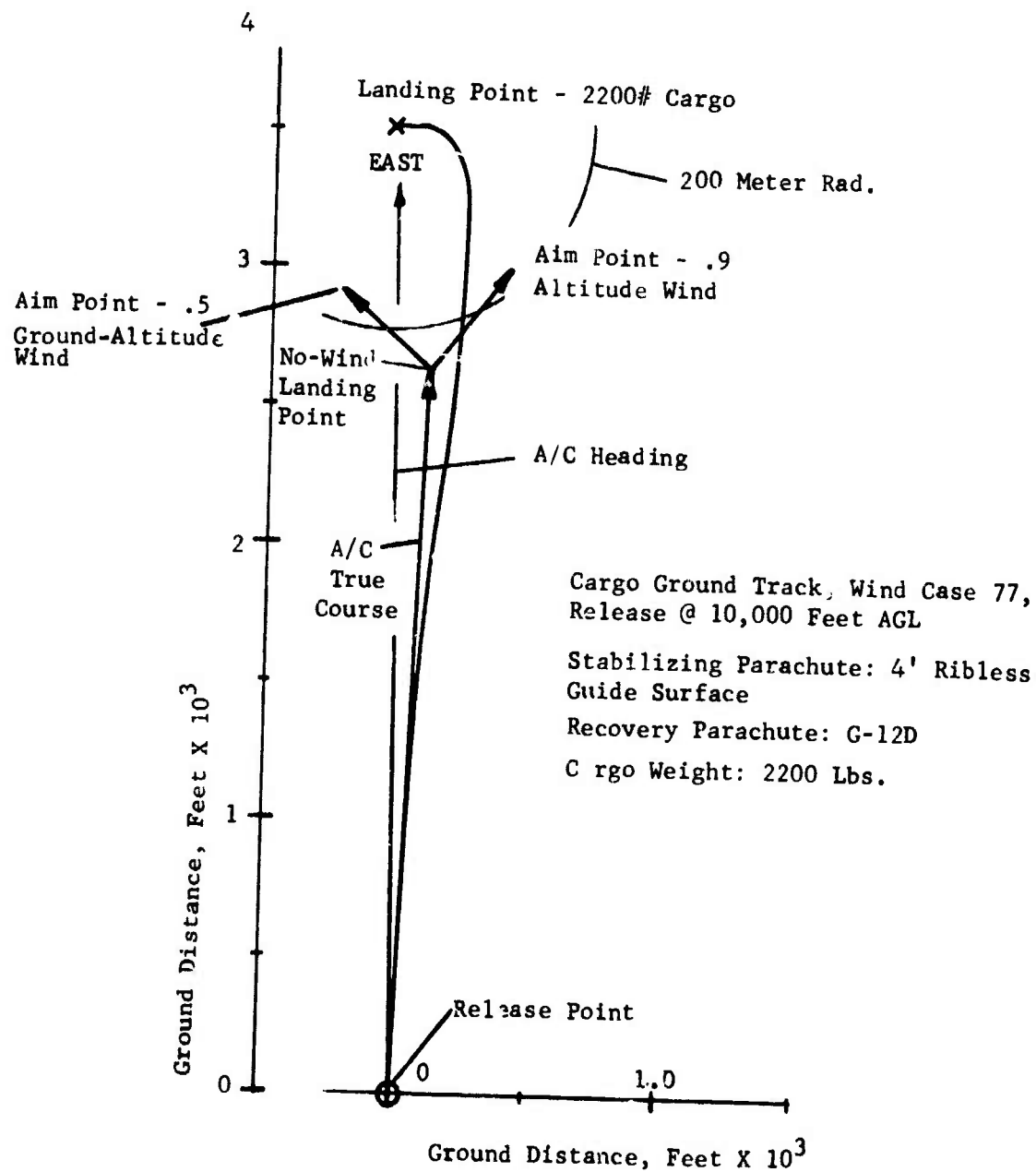


Figure 30

Cargo Ground Track - Wind Case 75 - Release @ 10,000 Feet AGL
 Stabilization Parachute - 4' Ribless Guide Surface
 Recovery Parachute: G-12D
 Cargo Weight: 2200 Lbs.

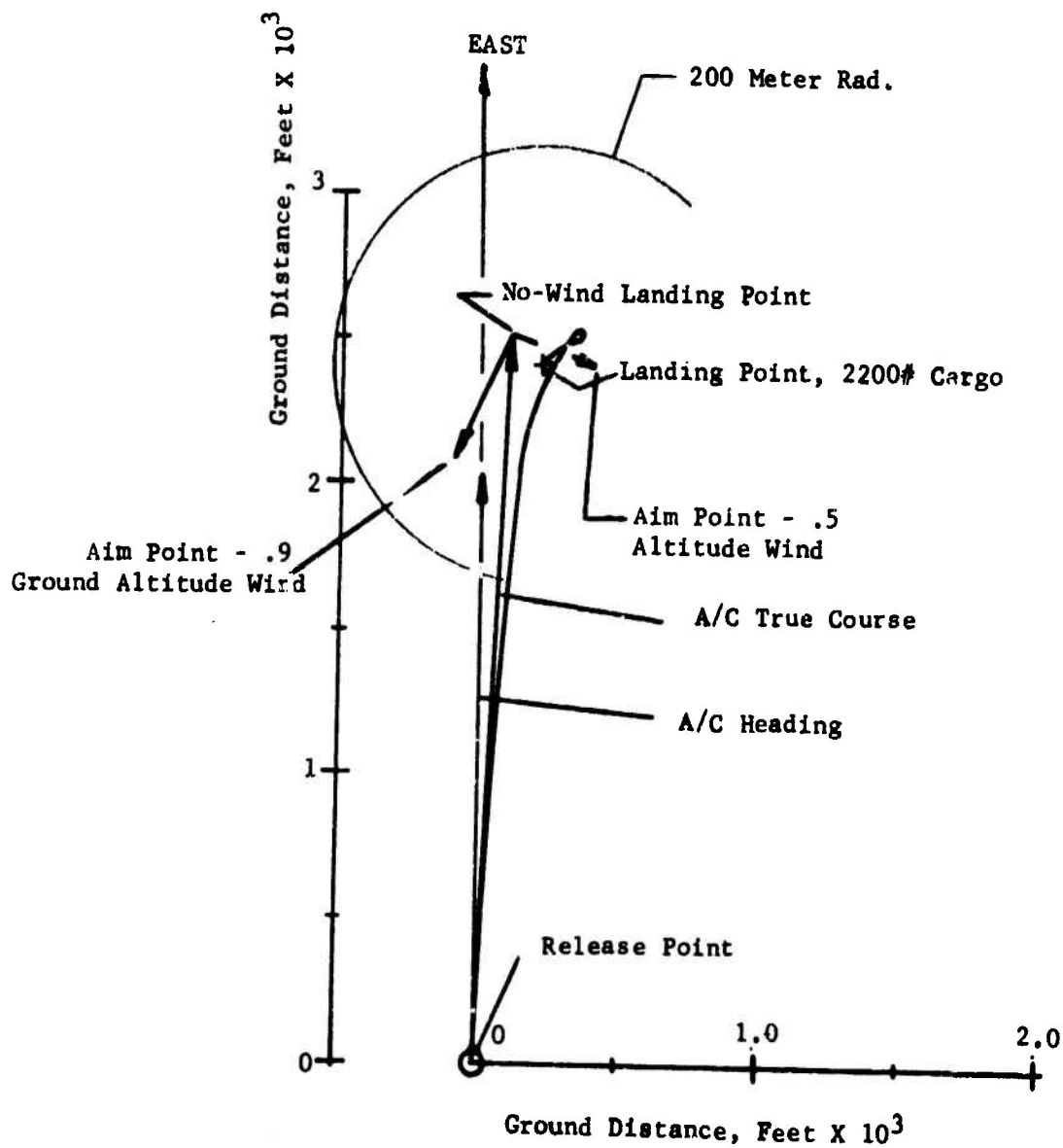


Figure 31

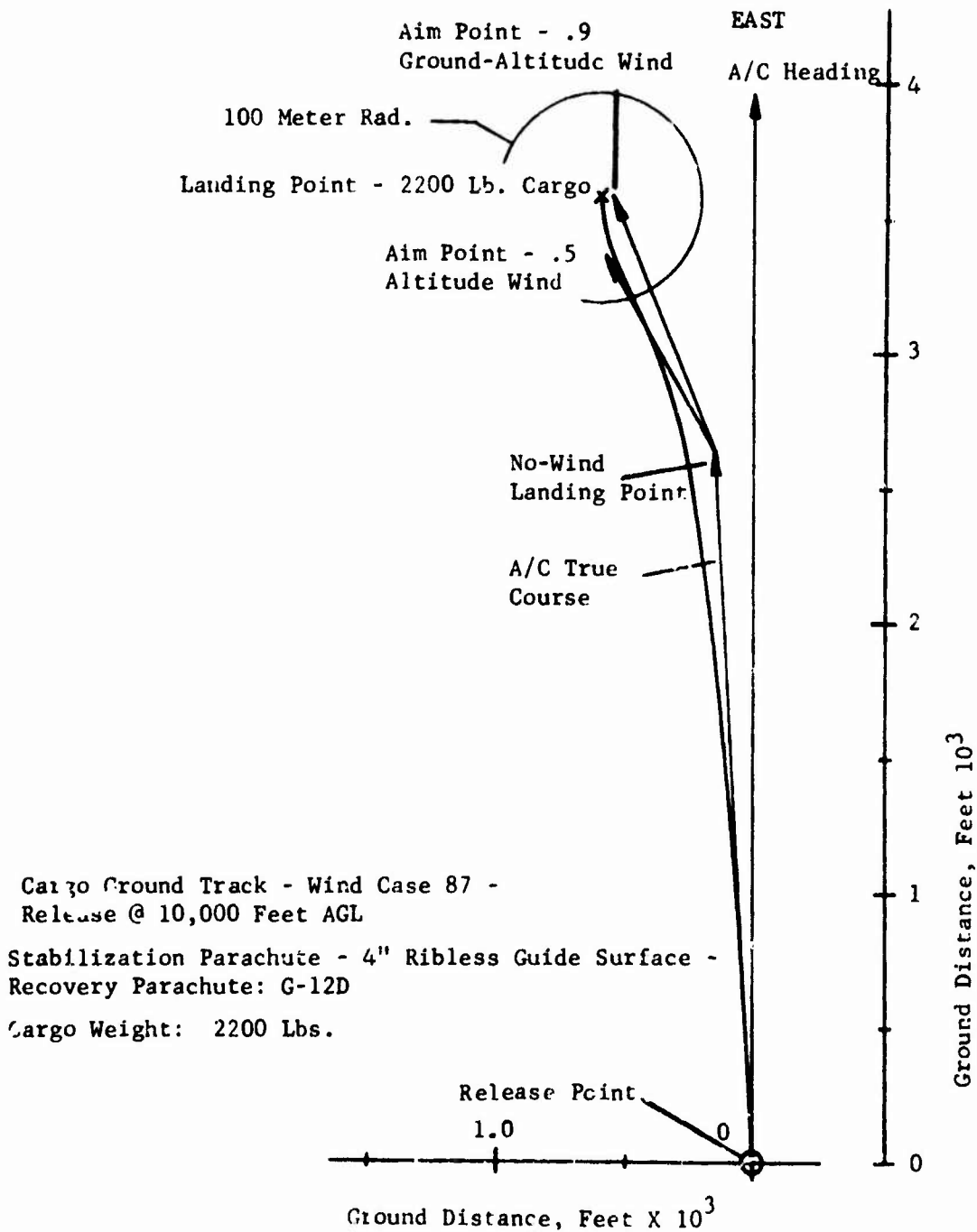


Figure 32

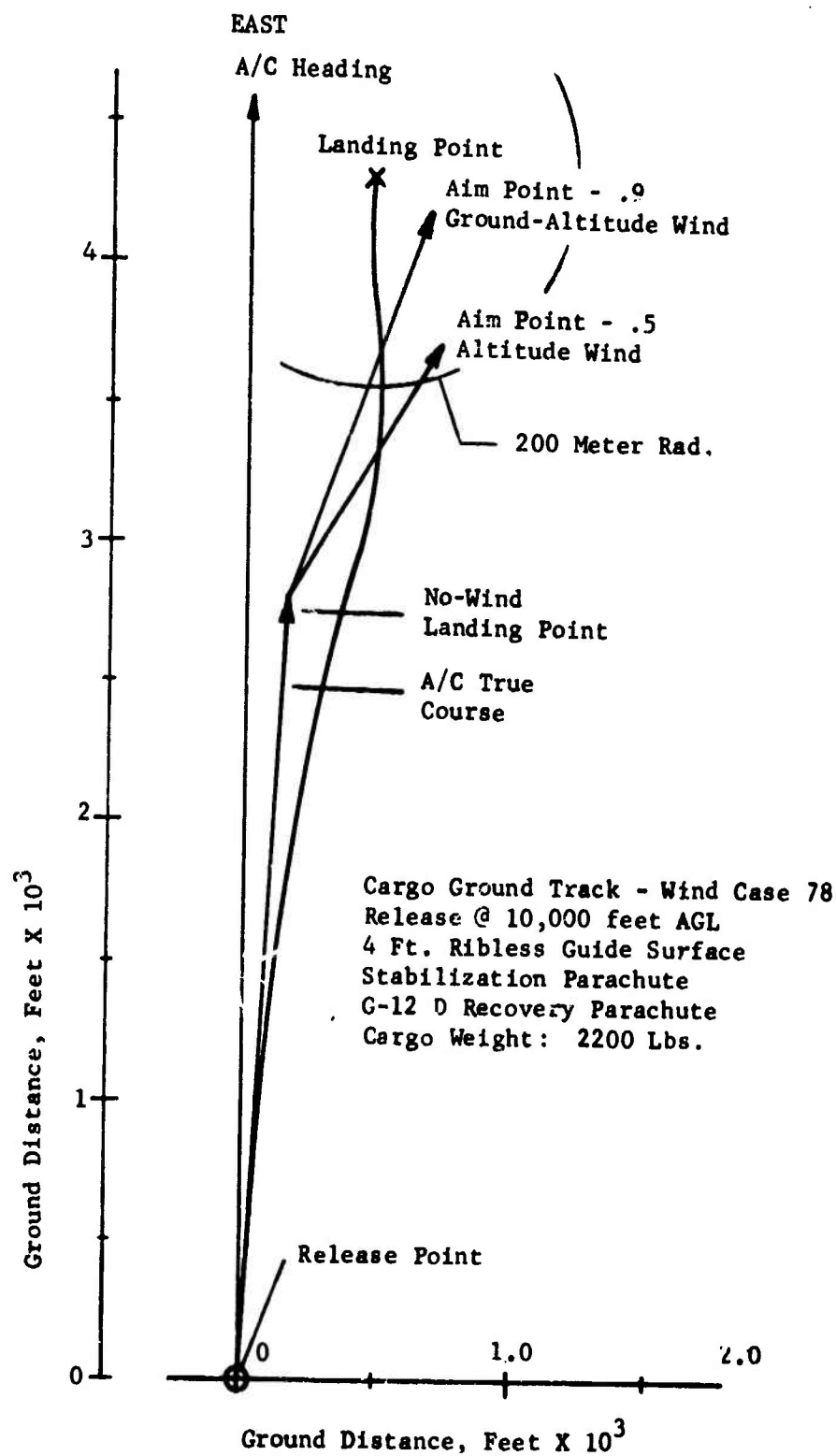


Figure 33

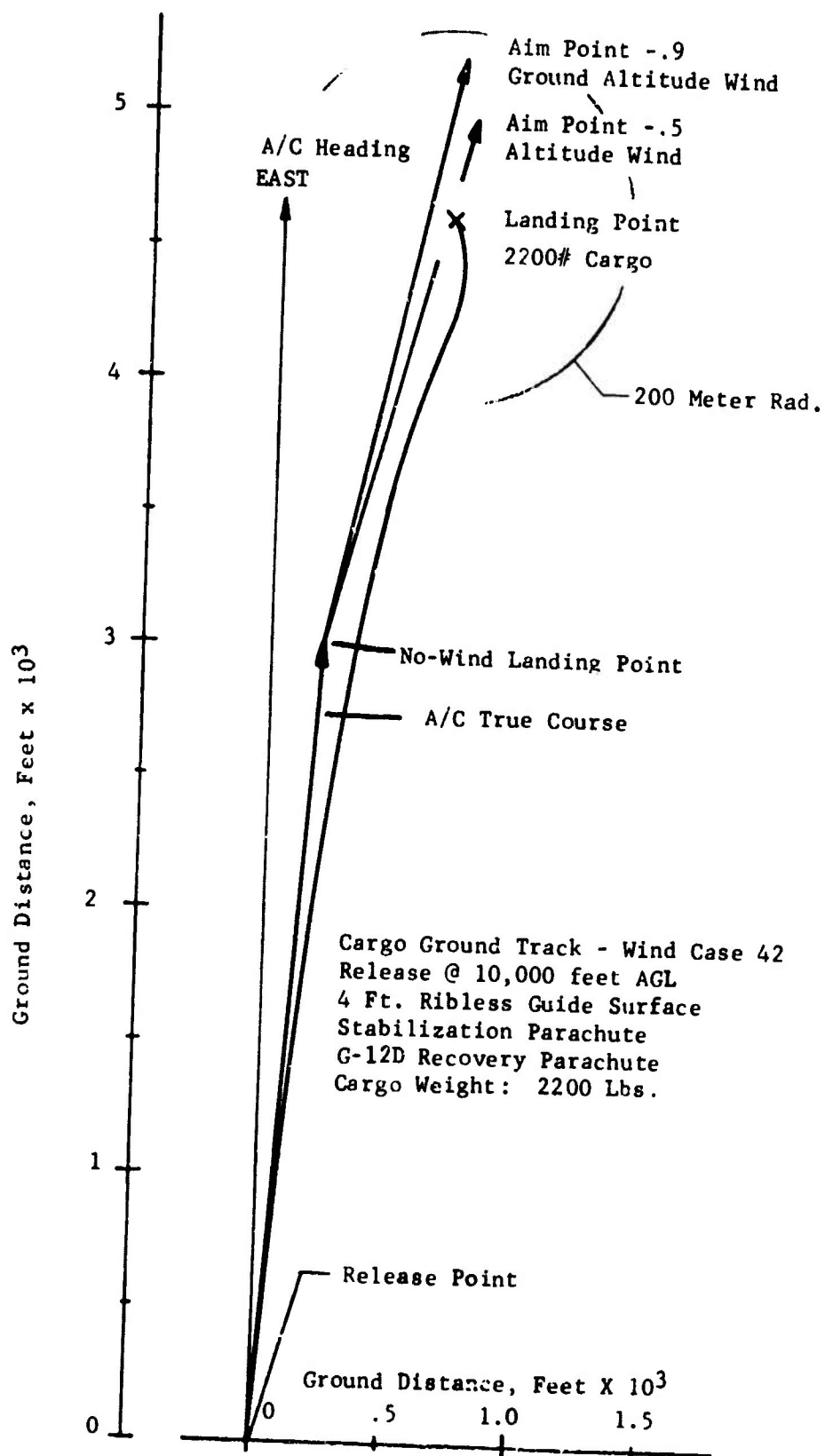


Figure 34

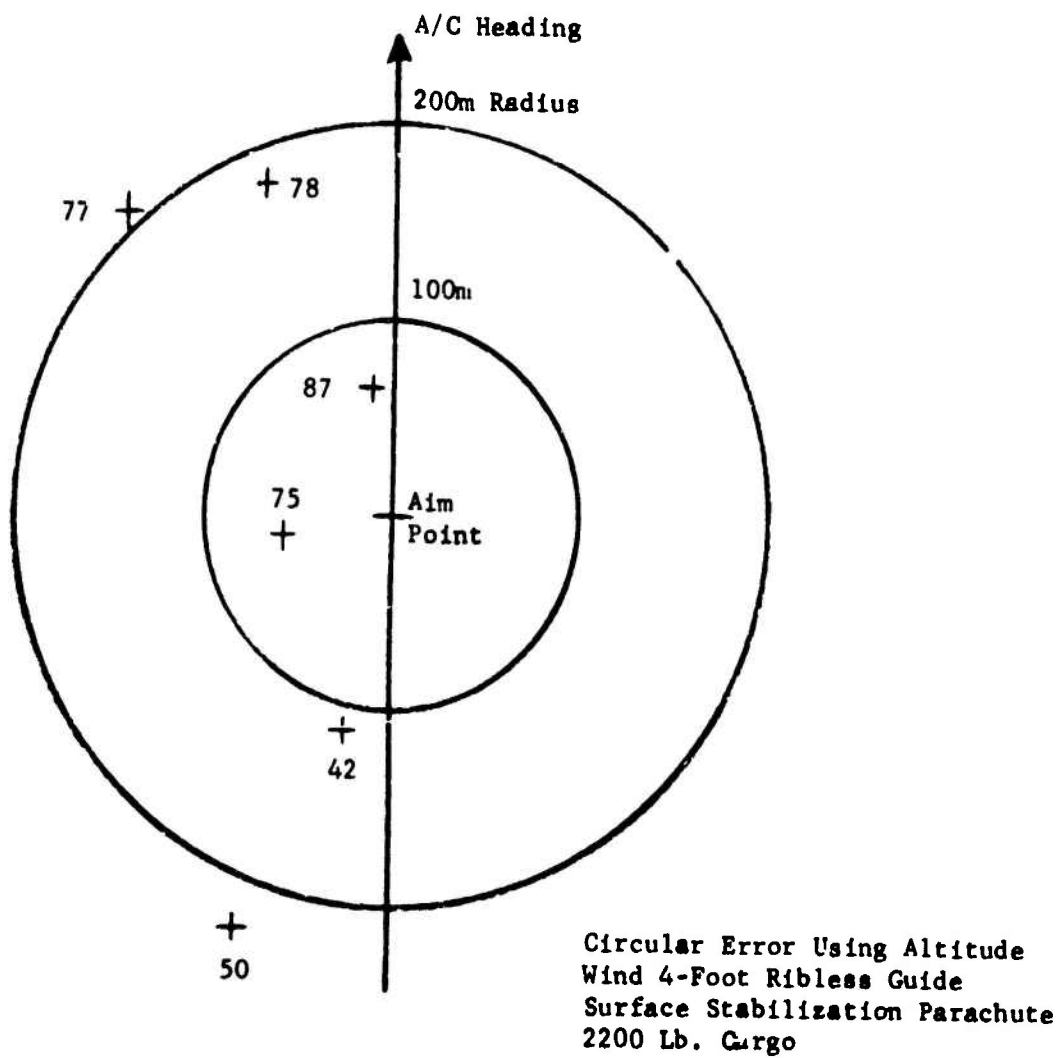
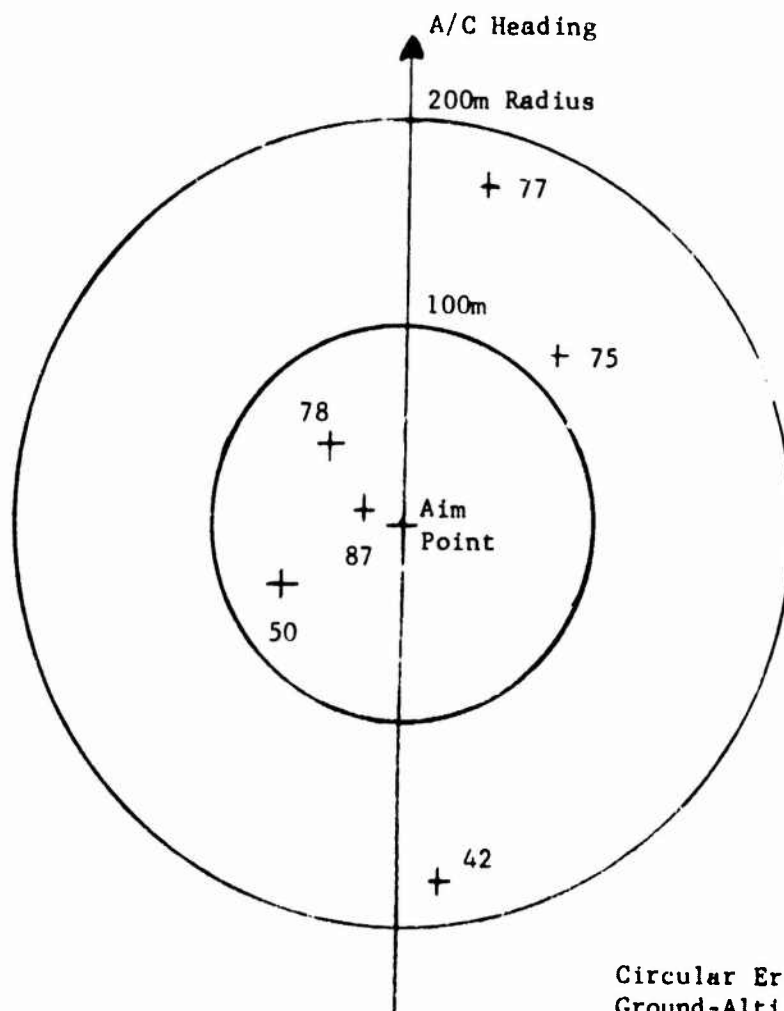
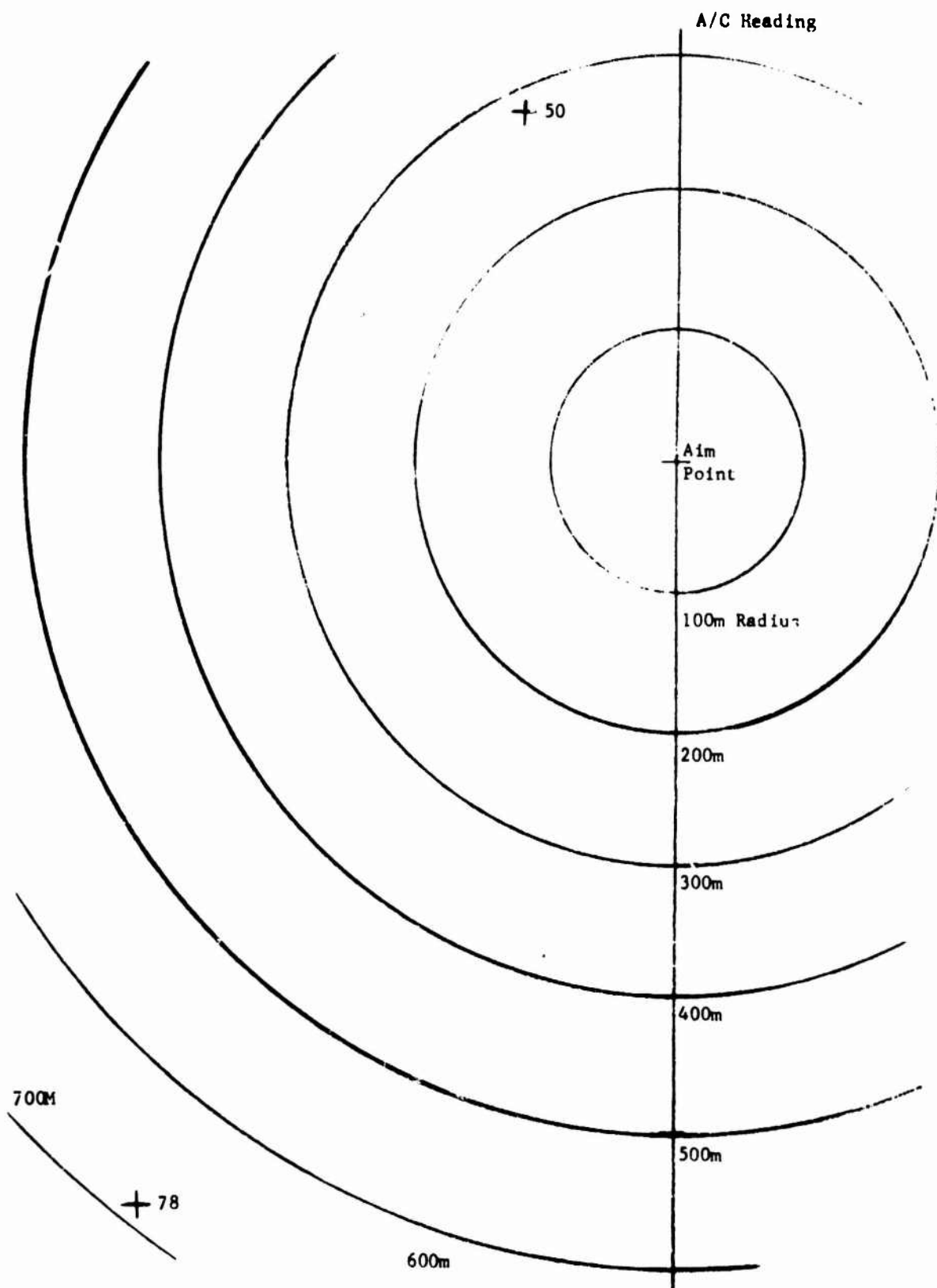


FIGURE 35



Circular Error Using
Ground-Altitude Wind,
4-Foot Ribless Guidance Surface
Stabilization Parachute
2200 Lb. Cargo

FIGURE 36



CIRCULAR ERROR - REEFED G-12D PARACHUTE - GROUND ALTITUDE WIND
FIGURE 37

3. Effect of Aircraft Heading

An assumption is implicit in the calculation of the release point (or, in the case of the simulations, the aim point) that the effects on the cargo trajectory can be separated into those from aircraft heading and speed, and those from the winds. Under this assumption, the aim points for different headings in the same wind conditions would describe a circle concentric about the circle of no-wind landing points. The no-wind landing points describe a circle because wind direction relative to the aircraft heading alters the true course upon which the no-wind landing point is plotted and also changes the initial cargo velocity upon which the no-wind distance is calculated. If the assumed effects are correct, the cargo landing points would also describe a circle about the no-wind landing points because if the trajectory effects were separable, the landing points would have a constant relationship with respect to the aim points.

To examine the validity of this postulate, computer runs were made using two surface wind cases, one case was a high velocity condition, the other below 15 knots. Each wind case was rotated through successive 90 degree increments relative to the aircraft heading. Each of the four resulting data sets for each wind case was input to the computer model, one wind case using the seven-foot flat circular stabilization parachute and the other using the four-foot ribless guide surface parachute. The results were plotted on a single chart for each wind case and they showed that the landing points did indeed describe a circle about the no-wind landing points. This means that the wind cases for the computer simulations may be used without bias, and more importantly, that empirically determined proportional wind factors may be found that will be independent of aircraft heading.

4. Effect of Stabilization Parachute

Several parachute configurations can be used for obtaining and maintaining stable flight for the A-22 container. The three-dimensional airdrop computer program was used to examine the performance of several of these parachute configurations with a 2200 lb. A-22 container. The results show the benefits to be gained by high velocity descent and that the most desirable system is one that provides the most rapid stable descent consistent with safe recovery of the cargo. The following table shows the maximum velocity achieved during the trajectory and the velocity 750 feet above the drop zone which is an altitude considered safe for deployment of the recovery parachute for each configuration.

Table 1 - Descent Velocities for Various Stabilization Parachute Configurations. - 2200 Lb. Cargo

Stabilization Parachute	Maximum Velocity (fps)	Velocity at Recovery Chute Deployment 750 ft. AGL (MSL) (fps)	Terminal Velocity at S.L. (fps)
4 Ft. Ribless Guide Surface	256	242	239
5.33 Ft. Ribbon	252	236	233
5.33 Ft. Ring Slot	249	234	231
7.0 Ft. Flat Circular	233	218	216
G-12D Keefed to 4 Ft.	95	84	83

The configurations were run for wind case 78. The landing points for the small parachutes were close together and had approximately the same time of fall of 54 seconds. On the other hand, the reefed G-12D spent over twice as long in the air (120 seconds), and had a large response to the wind that carried it away from the pattern of the others. (See Section IV-C-2) Reports of unreliable opening characteristics of the G-12D above velocities of 225 fps indicate that the 7.0 ft. diameter flat circular parachute would be required on 2200 lb. cargoes employing the G-12D as the recovery parachute. The opening properties of the 64 ft. annular ring parachute were not available for the study, but if this parachute is not subject to a similar limitation, the 4 ft. ribless guide surface stabilization parachute may be employed for stabilization. In general the 4 ft. ribless guide surface parachute is satisfactory as the stabilization parachute on all airdrop configurations except those cargoes weighing 1900 lbs. or more which employ the G-12D parachute for the recovery phase. For this latter case the 7 ft. flat circular parachute should be used as the stabilization parachute. (See footnote, Pg. 41)

5. Effect of Cargo Weight

Throughout the project, most of the analyses keyed on the 2200 lb. containerized cargo because this configuration would pose an upper limit as far as descent velocity is concerned and would also insure peak weight-to-volume efficiency in most cases. However, it was understood that variations in cargo weight could affect its trajectory, particularly since the parachute required to maintain stable flight during the descent phase is a function of cargo size and shape and not the weight of the contents. Thus the same stabilization configuration would be required for all weight loads but the higher drag-to-weight ratio of the lighter cargoes would slow their descent and increase their response to the wind.

In order to assess the influence of cargo weight on landing point accuracy, computer trajectories were run for a 2200 lb., 1500 lb., and 500 lb. cargo for each of three wind conditions. For one wind case, an additional cargo weight of 1000 lbs. was included. In each case, the 2200 lb., 1500 lb., and 1000 lb. loads were recovered with a G-12D parachute and the 500 lb. load was recovered with a G-13 parachute. All of the lighter cargos (1500 lb., 1000 lb., and 500 lb.) were stabilized with a 4 ft. ribless guide surface parachute because the lighter cargo weight allowed this smaller parachute to maintain a slow enough descent velocity consistent with safe opening of the recovery parachute.

Ground tracks and landing points for these simulations are shown in Figures 38, 39, and 40. The dispersion caused by varying the cargo weight was not as great as expected although the spread in wind case 50 did extend as far as approximately 800 ft. It should be recognized, however, that the computer simulations show results from a single point whereas in reality, cargos are released over a distance of approximately 1000 ft., and that some compensation for container weight variance might be made by proper load order in the aircraft. In general, lighter cargos, because of their higher drag-to-weight ratio, tend to decelerate faster and traverse smaller distances from their release point than the heavier cargos. Thus, if the lighter cargos are loaded forward in the aircraft, they will be released further down range and tend to converge on the heavier containers released first.

6. Effect of Cargo Release Altitude

Some variation in cargo trajectory will occur when the altitude of the release point is increased because the decreased air density will decrease the drag on the cargo and parachute. Computer runs were made for a release altitude of 15,000 ft. above mean sea level to a drop zone at 5000 ft. above mean sea level. The cargo weighed 2200 lbs. and was stabilized by a 7 ft. diameter flat circular parachute. Wind cases 32 and 50 were used because they exhibit large changes in direction and would thus represent extreme cases. The influence of increasing release altitude from 10,000 ft. to 15,000 ft. was minimal and the landing points were acceptably close to the aim points. The results are shown in Figures 41 and 42.

7. Effect of Air Temperature

Variations in air temperature will cause a corresponding change in air density which will in turn affect the drag on the cargo and parachute, thus influencing the trajectory of the cargo. In order to assess the magnitude of the temperature influence, computer runs were made for -20°F , 59°F , and 130°F holding cargo weight and wind profile constant. The temperature modification was made in the model by adjusting the cargo and parachute drag areas by the ratio of the absolute temperatures. The ground track and landing point results for wind case 32 are shown in Figure 43. The results for -20°F and 130°F are very close to those for the standard temperature (59°F), differing by less than 100 ft. This indicates that adjustments for atmospheric temperature conditions will not be needed.

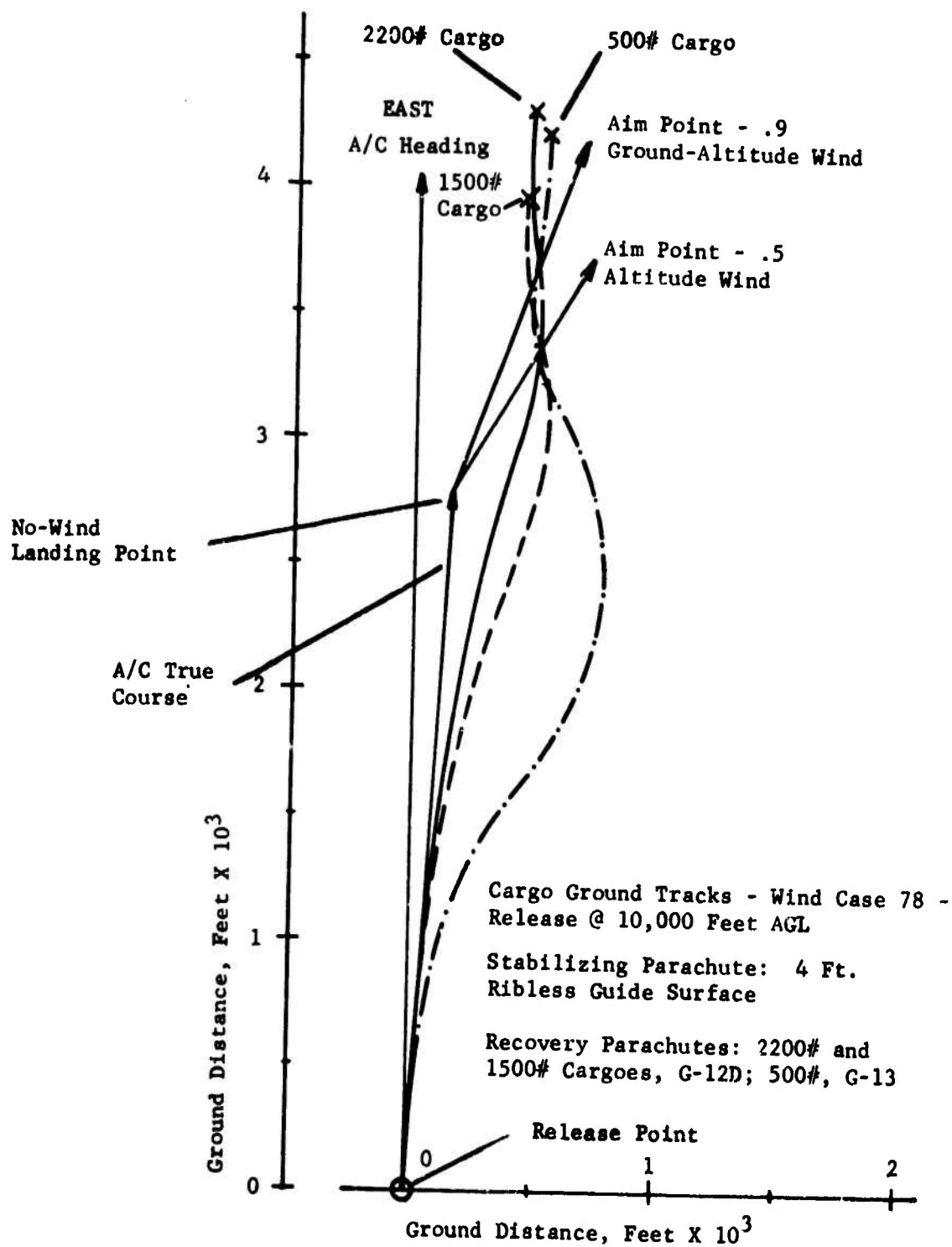


Figure 38

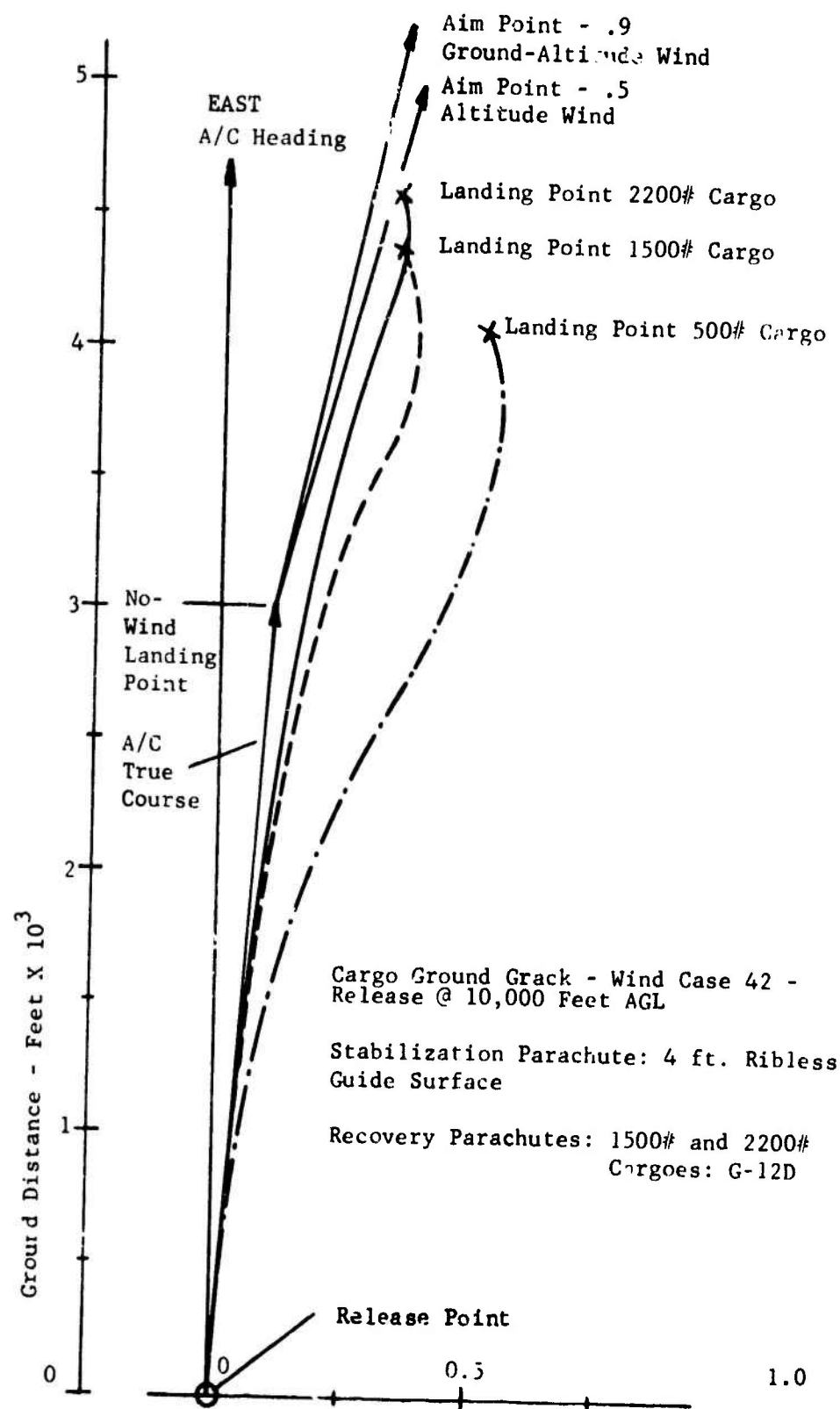


Figure 39

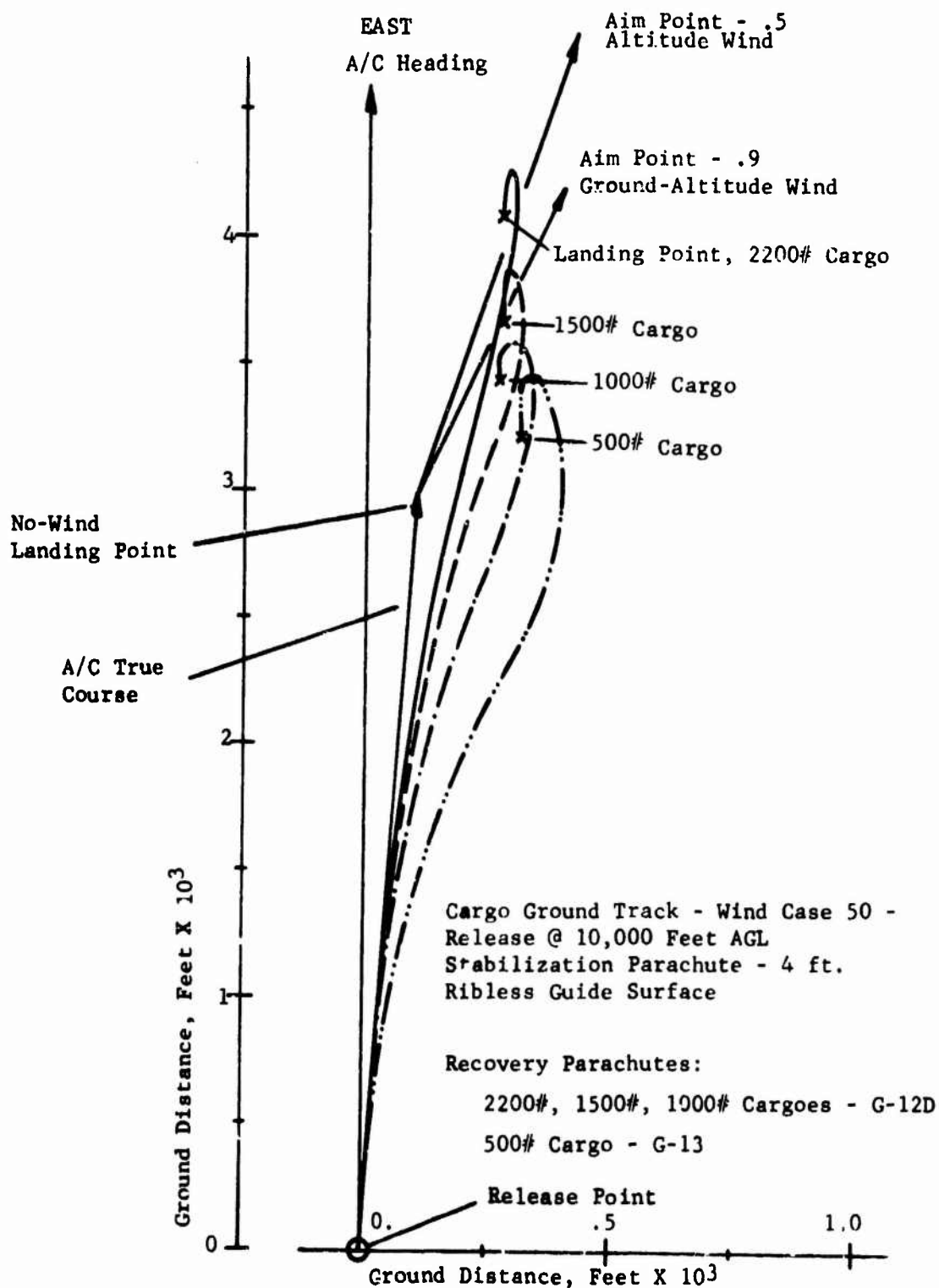


Figure 40

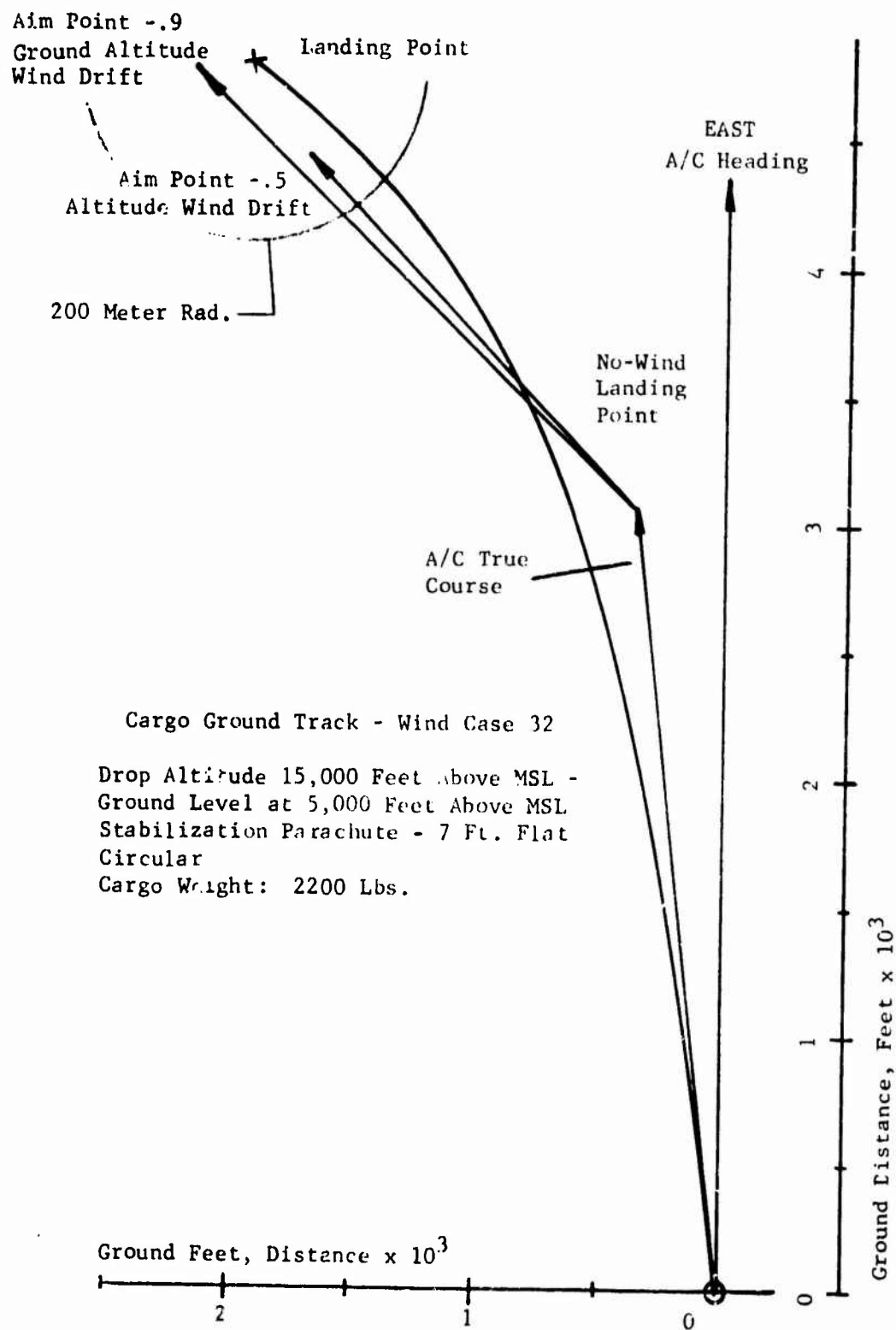


Figure 41

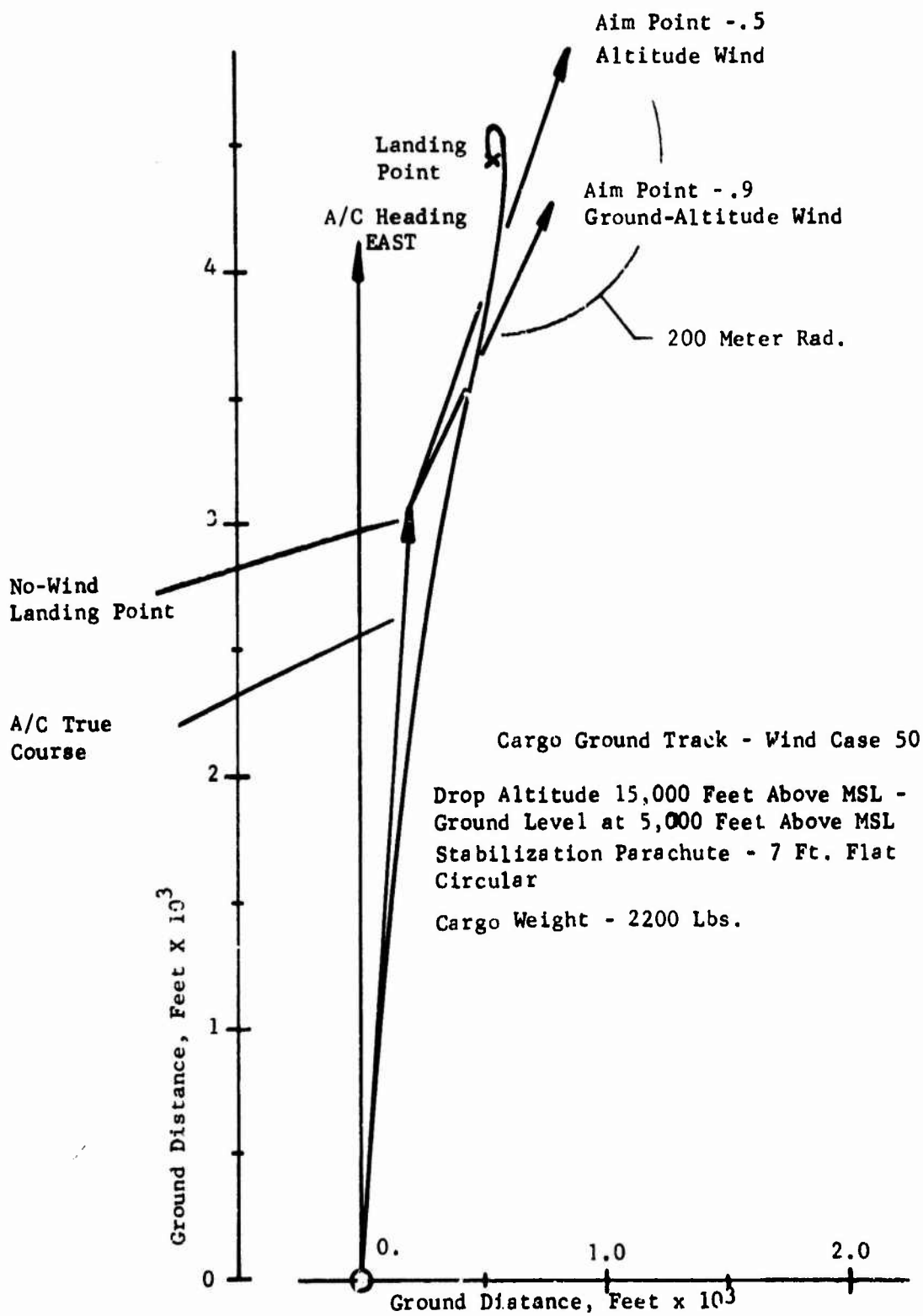


Figure 42

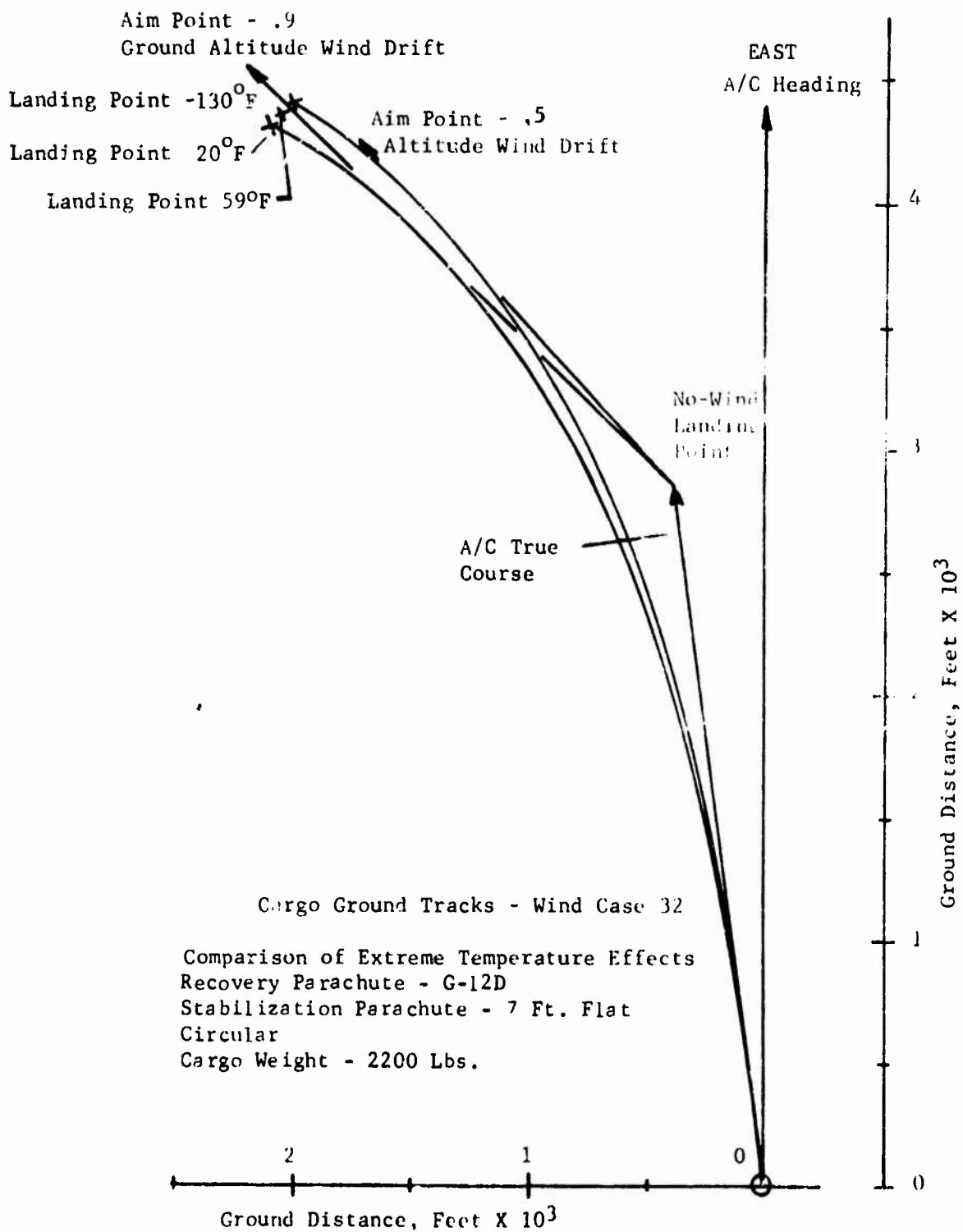


Figure 43

8. High Velocity vs. Low Velocity Impact

In order to examine the performance of the staged stabilization-recovery parachute system for use with high-velocity impact (90 fps), computer simulations were made using a 22 ft. ring slot extraction parachute for terminal recovery. The recovery parachute was initiated 1200 ft. above ground level to insure that terminal velocity would be reached but results showed that deployment could have been safely delayed until the cargo was 750 ft. above ground. Delaying the recovery until 750 ft. above ground would reduce the time in air by an additional three seconds.

Figures 44 and 45 show cargo ground tracks comparing the standard G-12D to the 22 ft. diameter ring slot parachute for identical cargo weights and wind conditions. As would be expected, the characteristics of the cargo motion under the influence of the wind are the same for both recovery chutes but the magnitude of the influence is less when using the high velocity recovery. However, because the recovery phase for either the high or low velocity impact technique is of such short duration, there is very little difference in the landing points. Thus there appears to be no significant advantage to the high-velocity impact method from the standpoint of accuracy. Furthermore, it would be possible to mix both types of container loads in the same aircraft with no significant effect on dispersion.

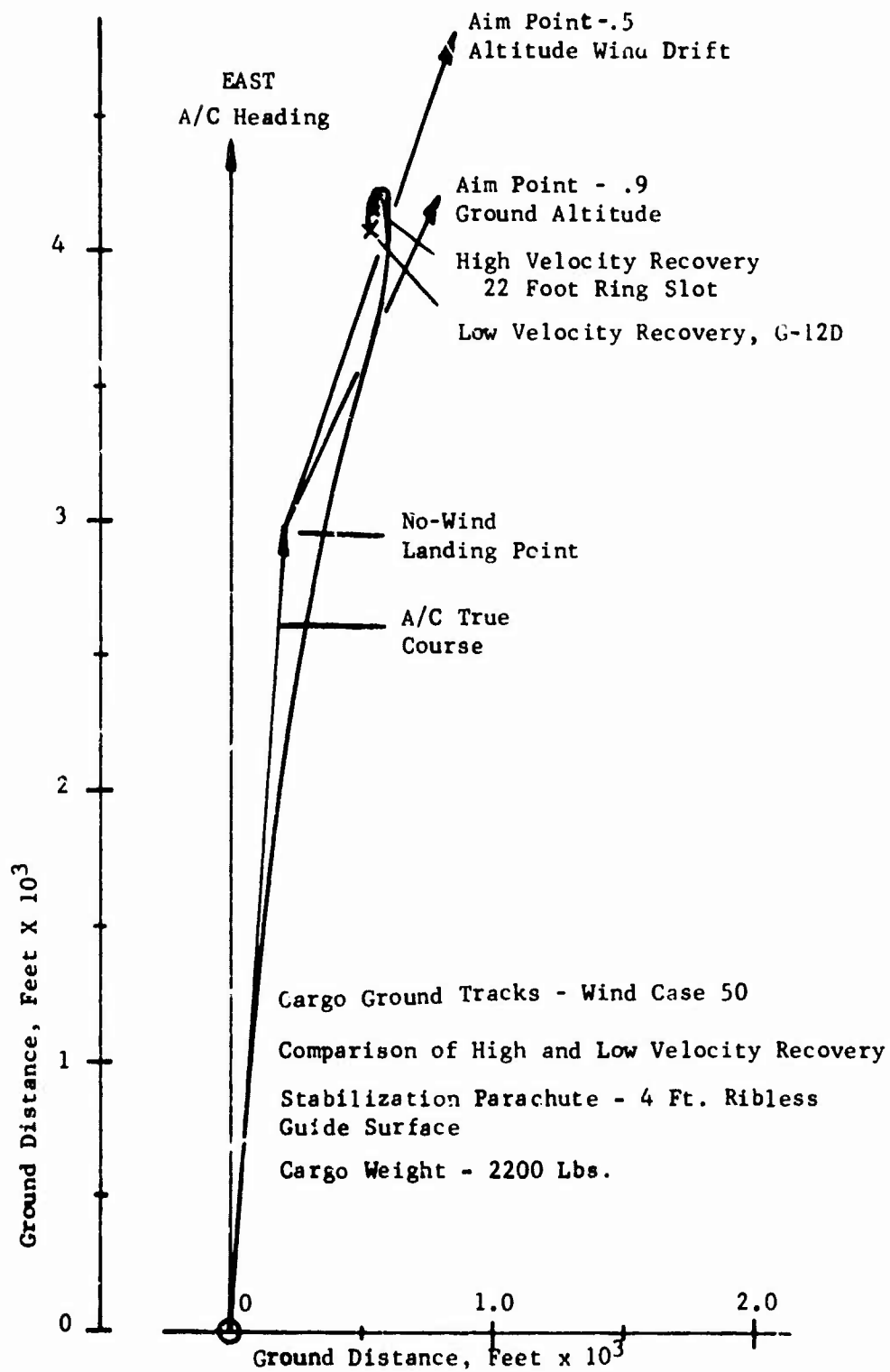


Figure 44

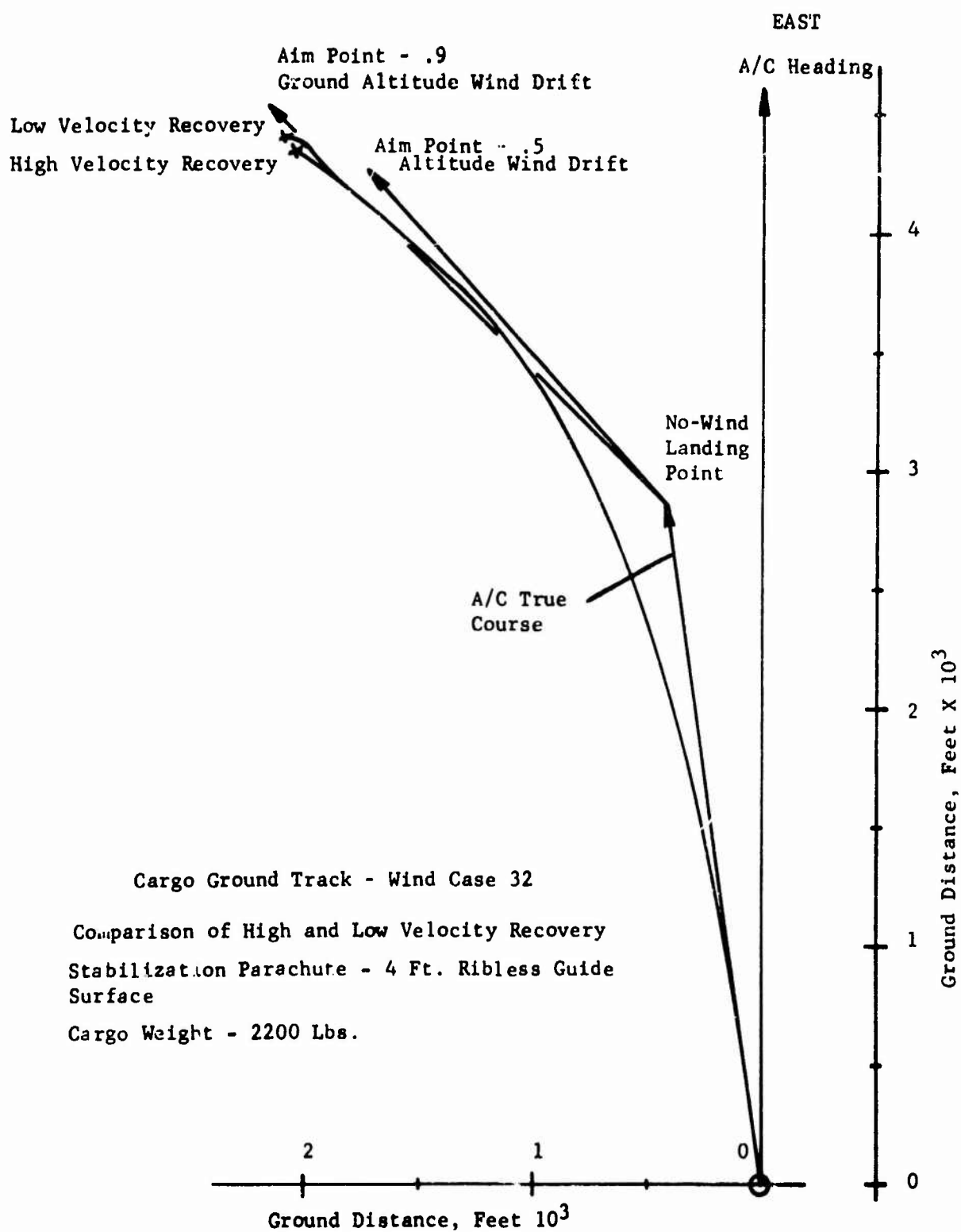


Figure 45

9. Statistics of Delivery Accuracy

Consider any observation that consists of measurements of two characteristics (x_i, y_i) that are selected at random from a population of such characteristics. The characteristics could, for example, be coordinates of bullet impact points from the aim point on a target or range and deflection distances of bombs from a target. If the two measurable characteristics are independent and normally distributed, the entire set of observations is distributed according to the bivariate normal distribution. The probability density as expressed by Burington and May (16) is

$$f(x, y) = \frac{1}{2\pi \sigma_x \sigma_y \sqrt{1-r^2}} e^{-G/2}$$

Where: σ_x, σ_y = standard deviation of x and y

$$G = \frac{1}{(1-r^2)} \left[\frac{(x-\bar{x})^2}{\sigma_x^2} - \frac{2r(x-\bar{x})(y-\bar{y})}{\sigma_x \sigma_y} + \frac{(y-\bar{y})^2}{\sigma_y^2} \right]$$

r = correlation coefficient between x and y

The probability that a point (x, y) falls in some region S is the integral of the probability density function over the entire surface, i.e.,

$$P(S) = \iint_S f(x, y) dx dy$$

In the case when $\sigma_x = \sigma_y = \sigma$ and $r=0$, the distribution is circular normal and the probability density can be expressed in terms of the radial error (ρ) such that

$$f(\rho) = (\rho/\sigma^2) e^{-G/2}$$

where

$$\rho^2 = (x-\bar{x})^2 + (y-\bar{y})^2$$

and

$$G = \left[\frac{(x-\bar{x})^2 + (y-\bar{y})^2}{\sigma^2} \right]$$

Considering the circle defined for some constant, C, where

$$(C \sigma)^2 = (x - \bar{x})^2 + (y - \bar{y})^2$$

the probability that a point (x, y) taken at random will fall in the circle is

$$P = 1 - e^{-C^2/2}$$

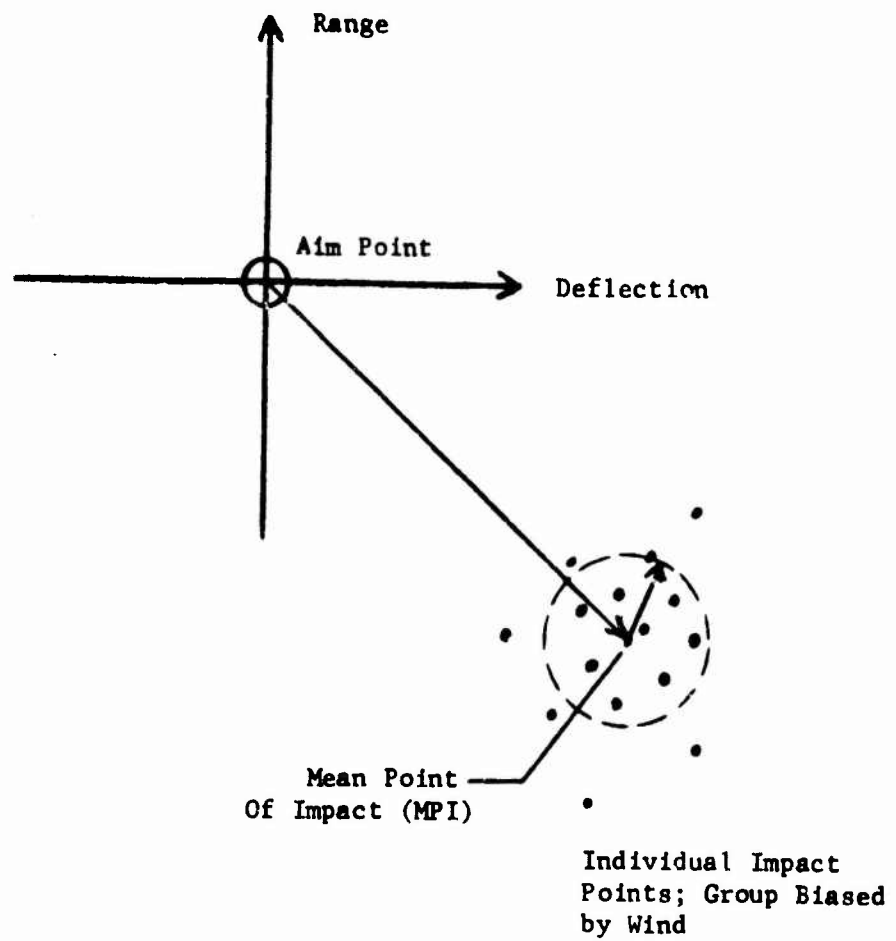
when $P = .5$, i.e., there is a 50% probability that the point (x, y) will fall within the circle, $C = 1.1774$. The radius of this 50% probability circle is called the Circular Error Probable (CEP) where:

$$CEP = 1.1774 \sigma$$

The accuracy of any cargo airdrop is subject to random variables associated with variations in initiating parachute deployment, variations in inflation time, and slight differences in cargo weight and shape as well as other factors which would prevent all cargos from following identical trajectories. Wind could be considered a random variable if a large enough time frame were analyzed so that the magnitude and direction of the wind could vary over the entire possible spectrum. However, for any particular group of cargos dropped from a single point at a single instant, or during a small time interval so that the wind profile remained constant during the drop, the wind would not serve to create a random error about the aim point (drop zone center for example), but to bias the entire group of impact points from the aim point.

Because of the bias introduced by the wind profile for a given group of cargos there is no guarantee that they will form a bivariate normal distribution about the aim point. However, errors in the physical properties of the cargos and the deployment characteristics of the parachutes create a bivariate normal distribution about the Mean Point of Impact (MPI). The MPI has as its components the arithmetic mean of the range and deflection components of the individual loads and the CEP for the group is a valid measure of the dispersion of individual cargos about this point because the trajectories are independent within the given wind profile. This concept is illustrated in Figure 46. The significance of the CEP in this context is that it defines a radius about the MPI within which half of the cargos dropped from the same point at the same time should impact. The location of the MPI defines the average miss distance for the cargos from the desired impact point.

The computer analyses performed during the program considered only the error introduced by the wind and did not consider the variation in



+ Release Point

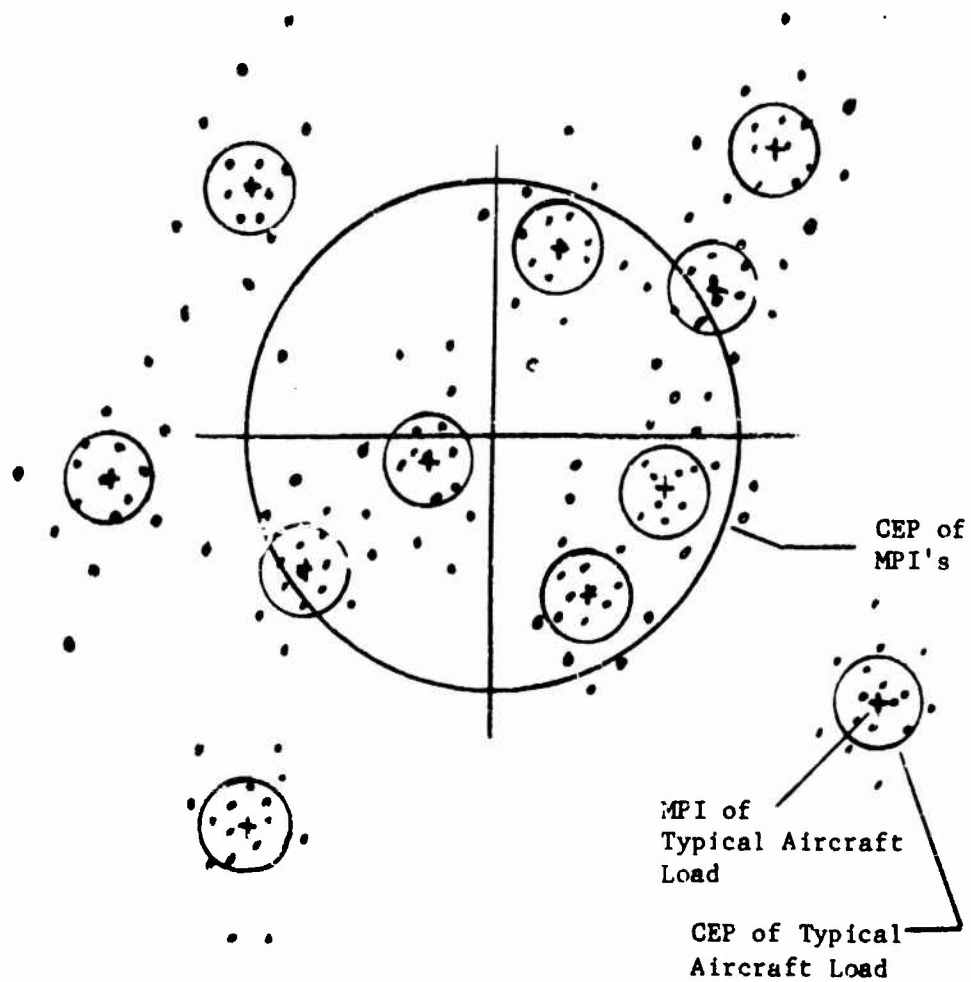
MEAN POINT OF IMPACT CONCEPT

FIGURE 46

parachute deployment initiation, opening time, etc. Thus, maintaining the single release point assumption for a given time, the trajectory generated by the computer is representative of the path to the MPI for each group of cargos. Calculation of these trajectories from the same release point, at the same aim point and through different wind profiles would result in a collection of MPI's for groups of cargos. If the variation of wind magnitude and direction were distributed normally about zero as a mean, the pattern would be bivariate normal and the CEP for the MPI's could be computed. This does not imply, however, that the CEP for MPI's is an indication of the spread of individual cargos. As a matter of fact, the spread of individual cargos about the aim point should not be expressed in terms of CEP because within each group, the trajectories are dependent upon the release conditions for the group and not independent with respect to all other trajectories.

The Joint Munitions Effectiveness Manual (JMEM)(17) defines CEP for bombing accuracy as the radius of a circle, with its center at the desired mean point of impact, containing half of the impact points of independently aimed bombs, or half of the MPI's resulting from independent aiming operations. In essence the airdrop operation is similar to bombing and the key points are that each load be dropped individually and that such drops be considered as independent events. However, when groups are considered such as with cluster or train bombing, scatter ammunition or container airdrop, the individual loads are not independently aimed. The process is similar to a marksman who fires once at a target with a shotgun. The accuracy of the shot is represented not by the individual pellets, but by the MPI of the pattern. If several more rounds are fired and each is aimed at the same target, the MPI's of the resulting patterns may be taken as normally distributed and it is the CEP of the MPI's which represents the accuracy of the weapon or delivery system while the CEP of the individual pellets about their respective MPI represents the dispersion of each group. In the case of airdrop operations, it is the CEP of MPI's which should be used to evaluate the accuracy of the delivery system and the CEP of the individual loads about their MPI which can be used to assess the errors in parachute deployment, opening and inflation as well as variation in load characteristics. This relationship is illustrated in Figure 47.

The CEP of MPI's can be used to evaluate the delivery effectiveness of the airdrop system because it is an indication of the ability to place groups of cargos on target. This accuracy and the effectiveness of delivering groups of cargos on target can be determined because representative wind profiles can be obtained. Dispersion of cargo groups about individual MPI's cannot be determined without knowledge of the reliability of parachute initiation, deployment and opening characteristics under operating conditions and the variation in physical load characteristics. These factors can only be determined accurately through empirical investigation.



CONCEPT OF CEP OF MPI'S

Figure 47

Throughout this discussion, it has been assumed that the distribution of individual cargos about MPI's is circular normal. In actual practice the patterns may be elliptical normal because the cargos are not released from a single point but along a path of finite length. This fact, however, does not alter the basic rationale behind the analysis because the elliptical distribution is still bivariate normal and the pattern can be reduced mathematically to an equivalent circular pattern about its MPI. The distribution of MPI's about the aim point could approach a circular normal distribution because it represents effective instantaneous releases from independent aim procedures. If the pattern is not circular normal, it can be reduced to an equivalent circular normal distribution and an equivalent CEP may be determined which in effect represents the radius of a circle that will contain 50% of the MPI's.

If the distribution is not circular normal, the range and deflection errors must be expressed independently and the parameters needed to describe the distribution are the Range Error Probable (REP) and Deflection Error Probable (DEP) which are related to the standard deviations of the range and deflection errors such that (see Ref. 18):

$$\text{REP} = .674 \sigma_{\text{range}}$$

$$\text{DEP} = .674 \sigma_{\text{deflection}}$$

Where:

$$\sigma_{\text{range}} = \sqrt{\frac{\sum_{i=1}^n (\Delta R_i)^2}{n-1}} \quad \text{and} \quad \sigma_{\text{deflection}} = \sqrt{\frac{\sum_{i=1}^n (\Delta D_i)^2}{n-1}}$$

ΔR_i , ΔD_i are respectively range and deflection errors of the impact points from the MPI

n = the number of impact points in the sample.

If the ratio of REP to DEP is nearly equal to unity, the CEP can be approximated by the relation:

$$\text{CEP} = .873 (\text{REP} + \text{DEP})$$

However, if DEP and REP differ by a factor of 2 or more the approximation becomes very poor.

The REP and DEP of the computer generated impact patterns for both the 4 ft. ribless guide surface parachute and 7 ft. flat circular parachute were calculated and used to determine an estimate for the equivalent CEP for 2200 lb. cargos. These are shown in Table 2. Although the sample size is small, it is sufficient to give insight to the relative accuracy provided by the candidate stabilization parachutes and wind adjustment factors.

TABLE 2 - EQUIVALENT CEP'S FOR VARIOUS AIRDROP CONFIGURATIONS

Configuration (All use G-12D For Terminal Recovery)	REP (Meters)	DEP (Meters)	REP / DEP	Equivalent CEP (meters)
7 ft. Flat Circular Parachute; Altitude Wind Adjustment	129.0	74.8	1.73	178
7 Ft. Flat Circular Parachute; Ground-Alt, Wind Adjustment	77.9	83.0	.94	140
4 Ft. Ribless Guide Parachute; Altitude Wind Adjustment	102.2	58.4	1.75	140
4 Ft. Ribless Guide Parachute; Ground-Alt. Wind Adjustment	82.5	37.5	2.2	104

Another comparative measure of delivery accuracy indicated by the computer results is the arithmetic mean of the radial errors of the candidate systems which gives an indication of the average miss distances of the cargo groups. These are shown in Table 3.

TABLE 3 - MEAN RADIAL ERROR FOR VARIOUS AIRDROP CONFIGURATIONS

Configuration (All Use G-12D For Terminal Recovery)	Mean Radial Error (meters)
7 Ft. Flat Circular Parachute; Altitude Wind Adjustment	180
7 Ft. Flat Circular Parachute; Ground-Alt. Wind Adjustment	148
4 Ft. Ribless Guide Parachute; Altitude Wind Adjustment	147
4 Ft. Ribless Guide Parachute; Ground-Alt. Wind Adjustment	107
Reefed G-12D Parachute	484

10. Summary of Parametric Effects

In the simulation studies the cargo impact point was obtained by computing the response of the cargos to actual wind conditions where the wind was modeled by inputting direction and velocity at 25 meter increments of height above the drop zone. Several other parameters which affect the cargo trajectories were introduced by using fixed routines or allowances which represent fairly well the effect these parameters have on the trajectories. In most instances these parametric effects were fixed and the dispersion of the impact points about the aim point shown in the computed results is due to variations in wind conditions. In high level airdrops the wind effects are so much greater than any other parameter that this approach is justified. An effective CEP based upon this method of simulation was computed and is discussed in the preceding section. In this section the effects of variations in other parameters is discussed. The effects are related to the dispersion they cause in the individual impact points and do not, therefore, effect the CEP estimates made in the preceding section. The more important parameters and their effects on the impact point is treated below.

a. Staging Height

This is the height above the drop zone where a signal is generated to begin deployment of the recovery parachute. The simulations have conclusively shown that the shorter the drop time the greater the accuracy of the airdrop system. The staging height is the transition point between the high velocity and low velocity descent phases, therefore, as much descent as possible should be made at the high velocity to minimize the total descent time. In most simulations the staging height was set at 750 feet. This appears satisfactory for most situations but tests may show that this can be reduced to perhaps 500 feet. Factors that determine the staging height are the accuracy of the PARS system (height sensor), the deployment and inflation properties of the recovery parachute, and the weight to drag ratio of the system with the parachute fully inflated. Sufficient time and space must be allowed for the recovery system to deploy and bring the system to a safe descent rate.

The 2200 pound container using a 4 ft. ribless guide surface stabilization parachute represents a limit case because the descent rate in the stabilization phase is maximum for this configuration. Here the descent velocity is 242 fps just before staging and 34 fps just before touchdown if a G-12D or its equivalent is used for recovery. Assume that the landing is made in a maximum 15 knot wind (25 fps) and the drift rate of the system is constant at the velocity of the wind. This is a conservative approach since it is known that it takes considerable time to reach this steady state condition. The descent time saved by lowering the staging height one (1) foot is:

$$\Delta t = \frac{1}{34} - \frac{1}{242} = .0252 \text{ sec.}$$

The reduction in horizontal drift due to this saving in descent time is:

$$\begin{aligned}\Delta S &= .0252 \times 25 \\ &= .62 \text{ feet}\end{aligned}$$

This is a substantial value and shows the importance of keeping the staging height as low as possible. The direction of this travel would be random about the impact point so in some cases the miss distance from the aim point would be increased while in others it would be decreased. Prediction of the impact point is improved, if this effect is minimized. In the ideal system touchdown occurs at the instant the cargo first reaches a safe touchdown velocity and efforts should be made to adjust the staging point to achieve this mode of performance.

b. Cargo Release Velocity

This is the velocity of the aircraft relative to the ground at the point of cargo release. A set of ground coordinates with the positive "X" direction coincident with aircraft heading was used in the simulations. In determining the "CARP" both in the simulations and in the real world airdrops, this velocity is computed and allowances are made so that the effects of this parameter have been included in the computed CEP's. In the study, cargo release velocities ranging from 180 fps to 350 fps were used.

c. Rotational Velocity of Cargo

This is the rotational velocity of the cargo due to tip-off from the aircraft ramp. Its affect, if any, is on the sizing of the stabilization parachute. The parachute must be large enough to prevent rolling up the parachute which would result in destruction of the cargo. The results of the study indicate that other considerations determine the size of the stabilization parachute. If tests confirm this conclusion this parameter will have a negligible influence on system performance.

d. Height Above Drop Zone

This is the height of the aircraft above the drop zone at the point of cargo release. The emphasis in the study was on high level airdrop performance. The majority of the simulations were computed for 10,000 foot levels above the drop zone at standard conditions and other release heights were not specifically simulated. The system accuracy could be expected to improve the lower the release height is above the drop, but only because there may be less uncertainty in making allowances for wind conditions. If the precise wind profile is known, system accuracy should be

independent of the release height. However, in the real world measuring the total wind profile is not practical and allowances based upon the wind at altitude, or at best, ground-altitude winds must be used. It might be argued that if the drop is made from a lower altitude, the estimate of the wind might be closer to actual conditions and system accuracy would be improved. This conclusion has not been substantiated quantitatively, therefore, only a qualitative statement can be made that drops made from lower heights above the drop zone should improve system accuracy.

e. Inflation Time of the Recovery Parachute

The inflation time of the recovery parachute affects the staging height discussed in Section (a). It is desirable that the recovery parachute open quickly and reliably. Quick opening is desired because this reduces the transition period from the low drag stabilization phase to the high drag recovery phase. Reliable opening is desired because this eliminates the need for increasing the staging height to allow for slow opening parachutes. This feature of the system should be a prime area of study in any test program for the system. Here again the effect is likely to be random and will not affect the mean point of impact (MPI). However, being able to lower the staging height, if the recovery parachute opens quickly and reliably, will substantially reduce the dispersion about the mean point of impact. In the simulations made during the study a staging height of 750 feet was used in the majority of cases. Examination of the trajectories indicate that it may be possible to lower the staging height as much as 200 feet if opening of the recovery parachute is reliable and other factors such as sensing the height above the drop zone also are accurate and reliable.

f. Cargo Weight

The effect of cargo weight on system accuracy involves a number of considerations. In general the study shows that the size of the stabilization parachute is a function of container aerodynamics and not payload weight and the smallest parachute that can be employed for stabilization is a 4' ribless guide surface design or its equivalent. This means that the heavier the container the faster the descent velocity and the greater the system accuracy. This is true unless other considerations alter the rule. One such recognized case is the opening characteristics of the G-12D parachute. This parachute will not deploy properly above 225 fpc so the descent velocity must be controlled within this limit. This requires that on the loads weighing 1900 lbs. and above, a stabilization parachute larger than the 4' RGS design be employed with a corresponding sacrifice of accuracy.¹ This matter has been treated in the study and several simulations of lighter container airdrops were made. The results show that in general the heavier containers land closer to the aim point but there are some exceptions. It is impractical to evaluate this effect quantitatively without a large sample of

1. See footnote, page 41.

data. However, a qualitative conclusion can be drawn regarding the arrangement of mixed cargos in an aircraft load. Since the lighter containers slow down faster than the heavier ones, it is recommended that the heavy containers be placed at the aft most locations with the light containers forward consistent with aircraft center-of-gravity limitations. This should result in a compact grouping of the load at the drop zone.

g. Elevation of Drop Zone Above MSL

Simulations were run using wind cases 32 and 50. In case 32 the ground and altitude winds are approximately in the same direction while in case 50 they are in opposite directions and thus are representative of extreme conditions. The winds in the 0.0 to 10,000 foot spectrum were used but the densities and temperatures in the 5000 to 15,000 foot spectrum were applied and the change in the miss distance from the aim point was determined. The results are shown in Figures 41 and 42 and summarized in Table 4.

TABLE 4 - SUMMARY OF ALTITUDE EFFECTS ON MISS DISTANCE

Winds Used To Locate Aim Point	Wind Case	Distance From Aim Point - Ft.		Δ Miss Distance - Ft.
		Altitude Above M.S.L		
		10,000 Ft.	15,000 Ft.	
Altitude	32	430	460	+ 30
	50	550	760	+ 210
Ground - Altitude	32	250	140	- 90
	50	280	335	+ 55

The results show that the change in the atmosphere at the increased altitude does affect the trajectories but on the basis of the data the effects cannot be categorized. It may be difficult to examine this problem by test because it would involve a change in test sites. The problem could be examined further with an expanded simulation program, but the resources of this program did not permit involvement in an investigation of this scope.

h. Accuracy of the Altitude Sensing Device

The altitude sensing device measures the height of the container above the drop zone and initiates the deployment of the recovery parachute at the appropriate height. From the discussion of staging height effects in Section IV-C-10-a it is obvious that the accuracy of this device should be as good as reasonably possible. Suppose for example the accuracy of the sensor is ± 50 feet. Fifty feet must be added to the ideal staging

height to assure deceleration to a safe landing velocity. But in estimating the effects of staging accuracy it must be assumed that the recovery parachute could also be deployed 50 feet early so in the limit situation the recovery parachute is deployed 100 feet above the ideal staging point due to the tolerance on the altitude sensor. This will increase the descent time and if the assumptions made in estimating the effects are the same as in Section IV-C-10-a the additional drift is:

$$\Delta S = .62 \times 100$$

$$= 62 \text{ feet}$$

This is a random effect that cannot be compensated for in computing the CARP, and illustrates the need for an accurate altitude sensor.

11. Comparative Cost Model

One method of evaluating candidate systems on a cost basis is to study the cost saving afforded by increased accuracy. The cost of new airdrop systems or new components added to an existing system could be examined in light of the savings created by increasing the number of loads landing safely on the drop zone, decreasing the cost of preparing and delivering cargos, increasing the efficiency of equipment recovery so that it becomes reusable at a cost less than procurement, etc. However, in some circumstances this technique breaks down because some changes in a system cannot be assessed merely in terms of dollars. For instance, the decision to drop container cargos from high levels rather than from standard CDS levels may reflect a sharp decrease in the probability that the aircraft will be destroyed by ground fire. Although it might be possible to place a dollar value on the aircraft it would not be possible to place a figure on the lives of the crew.

Another consideration in analyzing the cost effectiveness of candidates is the use of components, subsystems, or methods that are inventory items or parts of the standard airdrop procedure. Those components are essentially sunk costs and represent no increase in cost if used in the modified system. Thus, it should not be necessary to compute the actual system cost in order to compare candidates. Valid comparisons can be made by determining the increase or decrease in cost to the existing system relative to the increased or decreased performance over that existing system. The change in performance might possibly be expressed quantitatively such as the average increase or decrease in dollar value of the cargos delivered safely in the drop zone. For example, if it were found that the addition of a item costing \$X to the existing procedure allowed the average dollar value of the cargo delivered safely within the drop zone to increase by an amount greater than \$X, the modifications would be cost effective. However, some problems could result in trying to force a pure quantitative figure on system improvement.

The difficulty that arises with trying to apply a dollar value to the cargos delivered is that it does not consider the importance of the particular cargo to the troops being resupplied. During training operations, a lost cargo group may be written off at straight dollar value. However, in a combat situation, a small dollar value of ammunition or medical supplies may be a matter of life or death to ground troops in which case no meaningful dollar figure could be placed on lost cargo. In situations such as these, a simple "success - fail" criterion would be more meaningful. In other words, if a certain number of drops were delivered into a drop zone of designated size, the operation would be considered a success, if they were not, the operation would be called a failure. Cost increases to the system would be considered justified only as long as they were needed to achieve the accuracy required to deliver the cargos into the designated drop zone with the desired probability. Beyond that point, cost increases would not be justified.

An example of the above success-fail model can be expressed as follows. Suppose that it is assumed that the only way a mission could be considered a success is that there be at least a 50% probability that a cargo group be delivered within a drop zone whose effective radius were Y meters. In this case it could be stated that in order for the delivery system to be successful it must be capable of providing an equivalent CEP of Y meters. Also assume that there exists a system capable of providing an equivalent CEP of Y + D meters where D is a positive number. If there were several additions or modifications that could be made to the basic system which would allow it to provide the desired accuracy, the ones which represented the least cost for the improvement level of D meters is the one that should be chosen. In other words the modifications that provided the minimum desired accuracy for the least dollar increase are the ones that are the most cost effective. If desired, a more stringent accuracy requirement may be specified and the possible modifications examined to see if one exists that satisfies the new requirement. If so, the difference in cost between the system that provided the original requirement and the one that satisfies the more stringent one will give an indication of the level of monetary outlay needed to obtain a specific increase in accuracy.

One of the advantages of employing a model similar to the one discussed above is that it does not require the establishment of a quantitative value for the cargos in terms of the needs of the ground troops. It assumes that the importance to the troops could be infinite and that if a specified percentage of the cargos are not delivered within the drop zone of given size the operation is a failure. Thus, at any stage, only the candidates that satisfy the minimum accuracy requirements need be examined. Also, the technique supplies a comparative measure of candidates and considers only the components that are added to or subtracted from the basic system. It does not require that actual per-drop cost be computed and it does not clutter the computation with components that are common to all systems. It computes the change in cost. Standard components that are removed from the system are costed on the basis of current procurement and maintenance. New components are costed on the basis of projected production level procurement and maintenance plus the total development and introduction costs allocated over some estimated number of drops.

The model for computing the cost change can be represented schematically in the following manner. Assume that the total development and introduction cost is amortized over N drops. For a given accuracy level, the change in cost for the "ith" system is:

$$\Delta C_{T_i} = \sum_{j=1}^m \left\{ \frac{(C_{1j} + C_{2j})}{N x_j} + (x_j)(C_{3j} + C_{4j}) \right\} - \sum_{k=1}^n (x_k)(C_{5k} + C_{6k})$$

Where:

ΔC_{T_i} = the change in cost for the " i^{th} " system that meets the minimum accuracy requirements

C_{1_j} = total development cost of the j^{th} component added

C_{2_j} = total cost of introducing the j^{th} component into the inventory after development

C_{3_j} = procurement cost for j^{th} component added

C_{4_j} = per item storage cost over the useful life of the j^{th} component added

C_{5_k} = procurement cost of the k^{th} component withdrawn from inventory

C_{6_k} = per item storage cost over useful shelf life of the k^{th} component withdrawn from inventory.

m = total number of components added

n = total number components withdrawn

x_j = the number of j^{th} components needed per drop

x_k = the number of k^{th} components needed per drop

N = the number of drops over which development and introduction costs will be amortized

For each accuracy level, the system with the minimum ΔC_T will be the most cost-effective.

D. Recommended Configurations

The results of the investigations undertaken on this study lead to some conclusions regarding the physical make-up of the container airdrop assemblies that are most likely to perform satisfactorily when it becomes necessary to airdrop supplies from altitudes of 6,000 feet and more above the drop zone. These conclusions are based upon the results of extensive theoretical work performed during the program plus engineering judgment and a review of the reported experience of several researchers who have conducted experiments in container airdrop. The expected performance of a High Level Container Airdrop System, using these physical configurations and the airdrop procedures recommended in this report, need to be confirmed by actual test. A proposed test program has been prepared and furnished as a task of the program.

The studies clearly indicate the advantages of traversing the airspace as rapidly as possible, and that configurations employing separate stabilization parachutes as opposed to reefed recovery parachutes, perform much better in this respect. The recommended configurations, therefore, employ separate stabilization and recovery parachutes. The need is also clearly indicated for an accurate ground sensor which measures the height of the assembly above the drop zone and initiates the transition from the stabilization phase to the recovery or terminal phase of the airdrop.

The selection of the recovery parachute to be used on each container is largely a function of the container weight. There are several standard parachutes available for the purpose, and the container weights at which each can be employed overlap appreciably, especially if high velocity impact is used on those loads that can withstand these high impact decelerations. The stabilization parachutes, on the other hand, can be fairly well standardized and the same size parachute can be used for all container weight classes. This will be particularly true if it is found that the G-12D parachute can be successfully deployed at velocities up to 250 fps using a vent pull down configuration as recent experiments appear to indicate. Table 5 indicates a number of possible parachute configurations for the different weight containers.

Briefly, a typical High Level Container Airdrop would be accomplished as follows: The aircraft would be piloted to the proper Computed Airdrop Release Point (CARP) using a suitable navigational system. The Adverse Weather Aerial Delivery System (AWADS) navigational system is strongly recommended. The containers would be released from the aircraft by the gravity extraction method currently practiced in the CDS system. The stabilization parachutes would be deployed by static lines attached to the aircraft. The containers would traverse the airspace from the release point to a position over the drop zone stabilized in an attitude suitable for deployment of the

Table 5. HLCADS - RECOMMENDED PARACHUTE CONFIGURATIONS

CONTAINER WEIGHT CLASS LBS.	CONTAINER TYPE	RECOVERY PARACHUTE	STABILIZATION PARACHUTE
2200	A-22	G-12D	4' Ribless Guide Surface 5.33' Ring Slot 5.33 Ribbon Note 1
1900		or	
1500		AR64'	
1000		G-12D, AR64', Two G-13, 22' or 28' Ring Slot	
750	A-22 or	G-13, T-7	
500			
200	A-21		

Note 1. A 7' flat circular stabilization parachute may be required on containers weighing 1900 pounds and above if recovery parachute deployment problems are encountered at velocities in the 215 to 250 fps range.

recovery parachute. At an appropriate height above the drop zone, computed to be between 500 and 1000 feet and to be finalized by tests, the PARS height sensor would initiate the transition from the stabilization phase to recovery phase and the recovery parachute would be deployed. The recovery parachute decelerates the container to a final safe touchdown velocity just prior to touchdown. This concept is illustrated in Figure 48. Figure 49 shows the container on its stabilization parachute and Figure 50 illustrates the final or recovery configuration.

HLCADS
HIGH LEVEL CONTAINER
AIRDROP SYSTEM

AIRCRAFT RESUMES
 NORMAL FLIGHT

HORIZONTAL SPREAD AFTER
 DISCHARGE APPROX 50 FT

10,000 FEET

8

APPROX VERTICAL
 DESCENT FROM
 8000 FT.

4

2

750 FT

100 FT

2720 FEET

STABILIZATION PARACHUTE
 4 FT DIAMETER

MAIN PARACHUTE
 64 FT DIAMETER

BALLISTIC
 STAGE

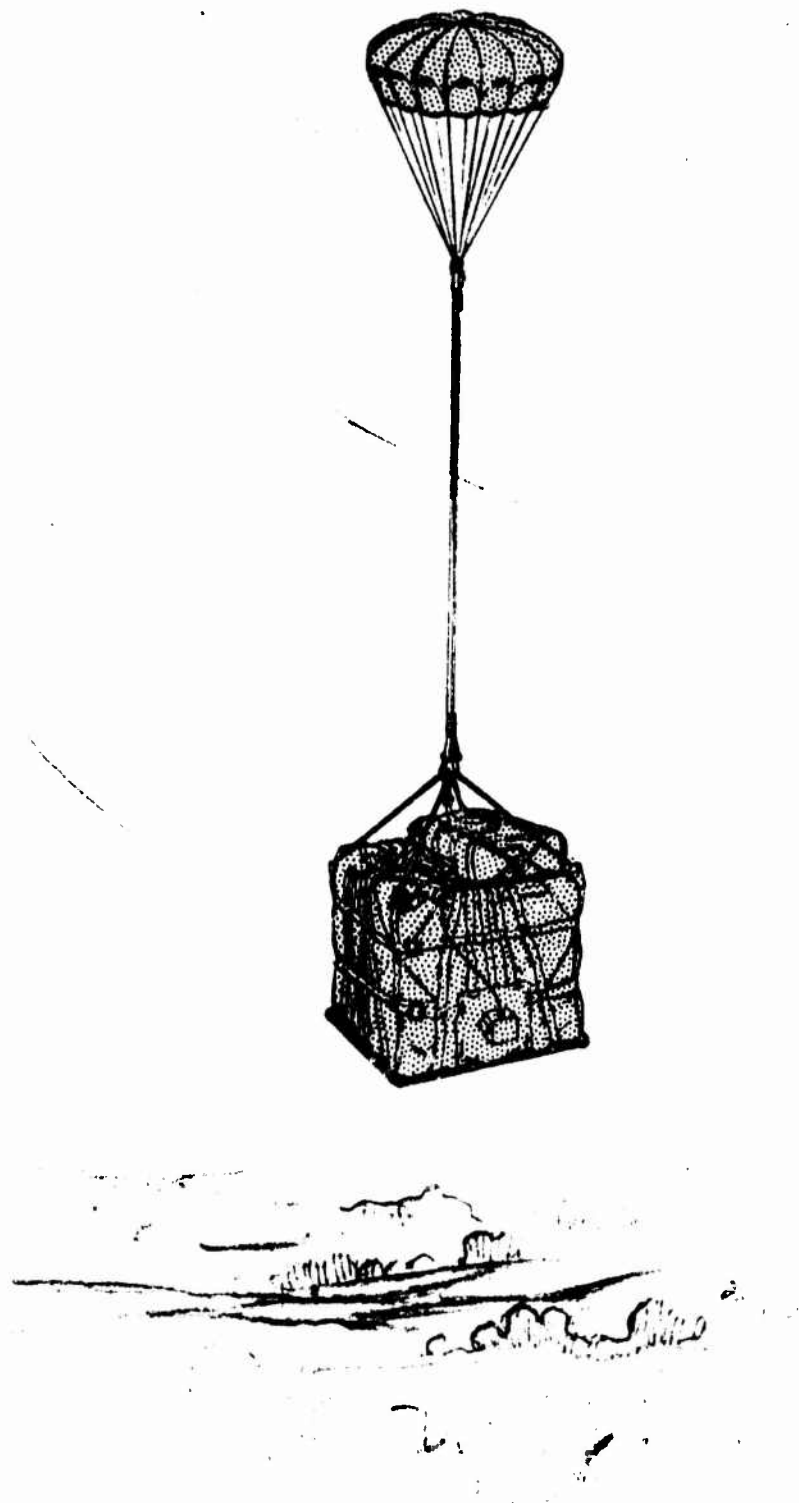
FLIGHT PATH

NOSE UP MAINTAINING LEVEL
 FLIGHT TO GRAVITY EJECT CARGO

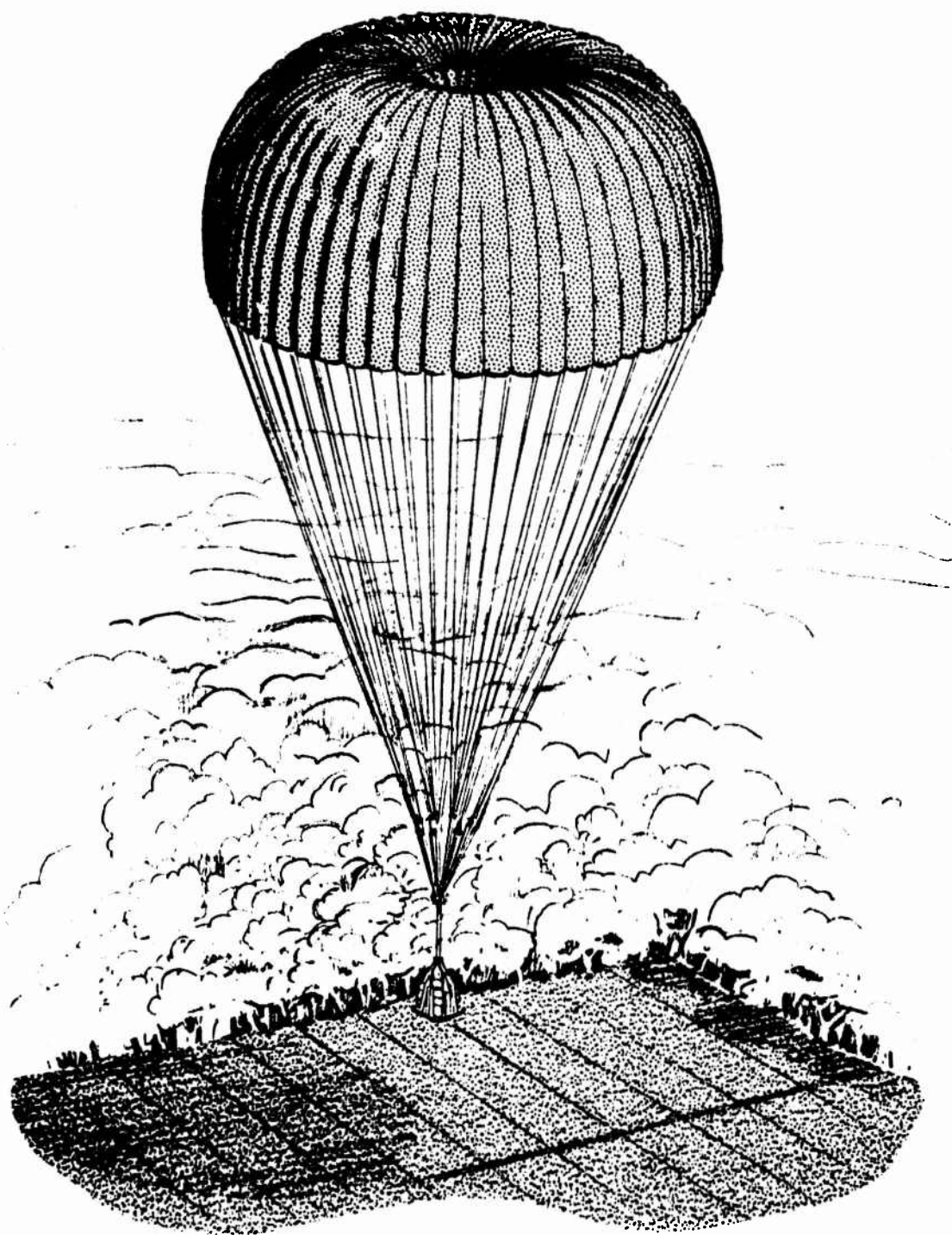
FULLY DEPLOYED
 MAIN PARACHUTE
 100 FT

SLOWS LOAD
 TO 33 FT / SECOND
 DESCENT RATE

PARS SYSTEM SIGNALS MAIN
 PARACHUTE DEPLOYMENT
 APPROX 750 FT FROM GROUND



HLCADS - STABILIZATION PHASE CONFIGURATION



HLCADS - RECOVERY PHASE CONFIGURATION

V. CONCLUSIONS AND RECOMMENDATIONS

Based on the results of the investigations and analyses performed during this study, several conclusions can be drawn as to the feasibility of dropping containerized cargo from high levels. In addition, recommendations based on theoretical performance can be made concerning features of the equipment and procedures necessary to achieve acceptable accuracy. Following are some of the conclusions that can be drawn from the findings of the study.

1. It is feasible to devise a container airdrop system capable of delivering cargos from levels of 10,000 ft. above the drop zone by the use of a stable descent velocity in excess of 200 fps and still decelerate the cargo using standard recovery parachutes for an impact at 33 fps or less. Furthermore, the study shows that separate parachutes for the high velocity descent and the recovery phases of the airdrop is strongly preferred.
2. An important result of the study shows that it is feasible to find a "proportional wind factor" which can be applied to the wind measured at the release altitude to adjust the cargo aim point so that terminal accuracies are within acceptable limits. This is truly significant because it means that interim or ground wind conditions need not be known to achieve acceptable accuracy from high level release points. If wind conditions at both the ground level and the release altitude are known, higher degrees of accuracy are attained and if information on ground wind conditions is available, it should be used.
3. Navigational equipment and procedures currently available are capable of computing and locating the proper air release point to produce accuracies on the order of .00 meters radius CEP. In actual tests of an interim high level airdrop system AWADS has proved its value.

Based on the findings of this project the following recommendations can be made for the near term solution to the problem.

1. Except for the height sensing equipment, the study shows that current inventory equipment can be used to accomplish an effective high level container airdrop capability. Also the current gravity extraction technique is adequate and is recommended for high level airdrop practice. Specifically the G-12D, G-13, the 22 ft. ring slot, and the new 64 ft. annular ring parachutes should be considered for the recovery parachutes. Small standard parachutes of a size indicated below should be used for the stabilization phase.

2. It is recommended that a two-parachute staged stabilization-recover system be used wherein a small stabilization parachute is deployed by a static line at tip-off and remain in use to stabilize the the container until it deploys the main recovery parachute approximately 750 ft. above ground level. All A-22 container cargos can be stabilized with a 4 ft. ribless guide surface parachute. Alternate stabilization parachutes could be a 5.33 ft. ring slot or 5.33 ft. ribbon parachute.
3. All high level container airdrop aircraft should be equipped with AWADS navigational equipment to insure that the air release point is calculated and located as accurately as possible based on up-to-the-minute wind conditions at the aircraft altitude.
4. Accurate height sensing equipment such as PARS should be employed to insure that the high velocity descent phase of the airdrop technique can continue as long as possible without endangering the safe recovery of the cargo.
5. It is recommended that insofar as aircraft C.G. considerations will permit, that mixed loads of light and heavy containers be arranged with the light containers forward in the aircraft. This results in minimizing the dispersion at the drop zone.
6. The resultant of the ground-altitude wind conditions should be used to compute the air release point. If ground wind conditions are not available, the most up to date wind condition at drop altitude should be used and will suffice.
7. A test program of sufficient magnitude should be instituted to verify the analyses of the various airdrop configurations and refine the techniques to optimize accuracy. Throughout the study, every effort was made to use accurate real-world environmental conditions coupled with proper mathematical models and computing techniques. However, no theoretical analysis can predict every possible factor that can be of significance in the field. In an effort to learn as much as possible within the time frame of this project, the emphasis was on insight rather than statistical significance and in some instances only limit cases were examined. It is believed that the results truly represent the type of performance to be expected from the recommended system, but only testing under actual environmental conditions will prove the system.
8. Cravity extraction as currently used in the CDS system is recommended for the high level container airdrop system. It is recommended that an explosive cutter be used to open the release gate instead of parachute activated knives.

While the above recommendations will be sufficient to give highly accurate results with little modification to current equipment and technique, increased performance would involve the long term development of new methods. Following are some considerations for the long term solution to the high altitude airdrop problem.

1. Develop a means of achieving a more rapid and reproducible method of extracting the cargo without causing inter-container interference.
2. Investigate the possibility of determining the complete wind profile from aircraft to drop zone immediately prior to instituting the airdrop. A high velocity "bomb" type probe equipped with sensitive motion sensing and transmitting equipment could be a possibility.
3. Investigate the cost effectiveness of using a streamlined, stable cargo container to eliminate need for a stabilization parachute, and along with this idea, develop a means of achieving reliable opening of a recovery parachute at velocities above 225-250 fps.

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